Towards a more authentic school science: grounding school science in the metascientific literature

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Towards a more authentic school Science:
Grounding school Science in the metascientific literature

A thesis submitted in fulfilment of the requirements for
award of the degree

Doctor of Philosophy

from

University of Wollongong

by

Gordon L. Brown
BSc, GradDipEd, MStudEd, MEd(hons)

Faculty of Education
1999
Declaration of Originality

I certify my authorship of the thesis submitted today entitled

Towards a more authentic school Science:
Grounding school Science in the metascientific literature

in terms of the University of Wollongong Course Rules set out in the Postgraduate Calendar.

Gordon L. Brown
8 March 1999
To my sons,
Jasper and Byron,
for the future of science education
is theirs.
Abstract

This study arose from the intersection of a number of concerns, chiefly: the need for informed decision making by the public, including scientists, in issues involving science and technology; the inadequacy of school science in preparing students for this task; the inadequacy of curriculum development processes in effectively using the combined expertise of curriculum stakeholders; and the strong interest of curriculum stakeholders in just what school science should be. Accordingly, the study set out to inform debates about each of these issues by addressing underlying causes. The particular underlying cause studied was the nature of school Science and how it could and should characterise that broader entity, science.

School science is traditionally characterised in one or two dimensions: as knowledge or processes or both. This has been the situation for so long the correspondence between the school subject Science and science itself tends not to be questioned. A relatively small number of authors in the education literatures have been critical of this situation, and so the present study sought to re-examine the characterisation of science for the school curriculum. However, an obvious rejoinder to the question, What is the nature of science? is another question, Whose view of science should be used? Given the disparity of views among science curriculum stakeholders, the present thesis sought not to add yet another view to the debate, but to 'map' the various views with the aim of providing a framework within which all stakeholders could add to informed discussion and decision making. The present thesis identified the metascientific literature as such a suitable basis, whose authority is recognised by stakeholders as a group. It comprises the publicly available, refereed scholarly body of research into the nature of science. Thus the present thesis interprets this as the central research question, How does the metascientific literature characterise science?

Through a semantic analysis of summary statements, such as definitions of science, the present thesis identified characterisations of science in the literature as being multidimensional, not uni- or bi-dimensional as traditionally used. In particular, the present thesis suggests knowledge, activity, purpose, structure, belief system and context as six interactive dimensions that account for characterisations of science in the metascientific literature. It further suggests that these dimensions provide a more robust basis for characterising science in the school curriculum.
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I have received the support, advice and encouragement of a number of friends, colleagues and family. In particular I must acknowledge the following. Mr John Collerson and Mr Brian Miller, of the Faculty of Education at the University of Western Sydney Macarthur, gave early and clear advice on linguistic analysis and functional grammar. My father, Mr Len Brown, proof read and gave editorial advice on the tables in Appendix A that improved their accuracy and readability. Dr Stewart Russell, of the Department of Science and Technology Studies (STS), University of Wollongong, gave advice on the state of the STS field and a draft of the discussion on context. He has also been liberal with his encouragement and the use of his personal library. My employer, the Faculty of Education at the University of Western Sydney Macarthur, has been generous with its allocation of computing resources, and provided a period of staff development leave that afforded me the intellectual perspective within which I was able to discern the six dimensions of characterisation from a substantial volume of reading. The University of Wollongong has provided, in a number of ways, the academic environment that has made this study so pleasurable and rewarding. The library has an impressive collection of metascientific and curriculum resources, and provides exemplary support for scholarship. The Faculty of Arts, through its departments of Science and Technology Studies, and Philosophy, has provided series of seminars that both informed this thesis and provided an intellectual climate that fostered scholarship. The Faculty of Education provided every encouragement for scholarship and growth, from its series of postgraduate colloquia to the personal interest from across the faculty.

Finally, any study such as this entails not only professional but considerable personal effort also. These efforts were not possible without the support and encouragement of my best friend and life partner, my wife Shayne.
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INTRODUCTION

This is a thesis about the nature of school Science. Specifically, it seeks to inform debate about what the nature of school Science could and should be. It interprets this debate as a question of why and how the general school curriculum can robustly represent, portray, or characterise science and how this characterisation can be improved. Of central concern to the present thesis is the argument that, to the extent that the subject called school Science corresponds to the field or discipline called science, the decisions by curriculum developers and curriculum stakeholders about that correspondence should be well informed. This thesis seeks to inform those decisions.

The nature of school Science is significant because of at least two debates. One arises from broad public concern about science education and education generally, and another because different groups of curriculum stakeholders in contemporary, pluralistic democracies have different views about what school Science should be. In response the present thesis seeks to inform these debates, and provide a framework that accommodates these diverse views by grounding discussion in the metascientific literature, that is, the published, peer-reviewed, publicly available body of scholarly analysis of science.

The present thesis pays only peripheral attention to factors other than the nature of science that can and do influence the nature of school Science, such as student readiness and interest, current issues, matters of learning, matters of teaching, or matters of curriculum implementation. These factors are important and legitimate issues for curriculum developers to consider, and will affect the present thesis and be affected by it. However, they are not the central issue here.

These introductory remarks introduce several terms that are important in the present thesis, such as characterise, robust and the general school curriculum. Their meanings here should be clarified. The term characterise is used to mean represent or portray the peculiar, typical, distinctive or distinguishing features or qualities of science (The Macquarie
The term robust is used here to mean strongly built (*The Macquarie Dictionary*), in the sense of being rigorous, soundly constructed and thoroughly grounded in scholarly analysis of science.

The term general is used to mean the *school curriculum provided for all students*. The school curriculum addressed by the present thesis is the curriculum for years K-12, that is, from kindergarten to the end of secondary schooling. It is possible for a school system to devise special curricula, such as for preparing particularly able students for tertiary science and technology studies, for students with learning difficulties, for a vocational program, and so forth. For such curricula, and even for K-12 generally, it may be argued that only some aspects or dimensions of science need be addressed at the school level. The present thesis will argue against this, but in any event the very possibility of specialised curricula is a distraction from the present purpose, which is how to differentiate the characteristics of science for various curriculum purposes when those purposes pre-suppose the nature of school Science. Therefore natures of differentiated school Sciences will not be addressed except to show that the present thesis applies to all school science curricula.

While this thesis claims to inform curriculum development generally, its focus is on curricula in contemporary pluralistic democracies, using the Australian context, and particularly New South Wales (NSW), to provide a related set of examples.

**Overview of the thesis**

In brief, this thesis argues that a suitable, indeed necessary, authority for deciding the nature of science in the school curriculum is the metascientific literature. Two of its premises are that, first, school Science needs to represent or characterise science more authentically or robustly, and secondly that this cannot be done unless the decision-making processes involving science curriculum stakeholders are improved. A sound grounding in the metascientific literature addresses both.

A semantic analysis of summary statements of science (ch. 4) shows that the metascientific literature characterises science in multiple dimensions, not just in the one or two (knowledge and/or processes) traditionally used in curriculum documents. The present analysis suggests six interdependent dimensions of characterisation: knowledge, activity,
structure, context, purpose and belief system. The six are developed in six dedicated chapters, one for each, by analysing the use of various elements used in the literature to characterise science. The findings of this analysis and theorising then lead to recommendations for the rationale and nature of science in the school curriculum. The scope of these recommendations is limited to the nature of school Science, and does not include questions of learning, teaching or curriculum implementation except as implications of the analysis.

The present thesis refers to the literature throughout, but it does so in several ways. Hence, the literature review (ch. 2), methodology discussion (ch. 3) and bibliography are linked. Their respective roles are to:

- direct the reader to the basis for the aim, method and data source;
- explain how the literature was analysed and the findings from this analysis were interpreted; and
- list the references used.

The term, the literature, is used here as a shorthand for the literatures of several research fields: science education, general education, curriculum, education policy, the sciences, history of science, philosophy of science, sociology of science, science policy, and fields within fields such as learning theory and the public understanding of science. The semantic analysis of summary statements takes its data from the metascientific literature, and educational argument takes its aim and context from the educational and metascientific literatures. The majority of sources used were scholarly sources, including books and journals on education, science and metascience. Other sources were articles in reference books, fiction, and curriculum and policy documents. The term metascientific literature is used here to mean literature about science: the statements and arguments about the nature of science. It includes the passages and chapters in the scientific literature that discuss the nature of science. More often, it means the texts, journals and indeed whole scholarly fields of study devoted to the nature of science, notably the history, philosophy, sociology and policy of science. Because the present thesis ultimately seeks a ‘mainstream’ view of science for the curriculum, it interprets the literature more broadly than would be
necessary for particular metascientific arguments. The criteria and procedures used in selecting from and reviewing the literature are discussed in the methodology chapter.

Some concerns and premises that preface the thesis

The purpose and approach of this thesis can be better introduced and understood by setting down some of the author’s motivating concerns and some presumptions or premises about the science curriculum. Broadly, these were concerns about science, society and the science curriculum. As issues they can all be found in the science education, curriculum and metascientific literatures, but the reasons why these and not some other valid issues arose are found in the prior experiences and orientations of the researcher:

To begin with, any researcher, no matter how unstructured or inductive, comes to fieldwork with some orienting ideas, foci, and tools ... At the outset ... we usually have at least a rudimentary conceptual framework, a set of general research questions, some notions about sampling, and some initial data gathering devices. (Miles & Huberman 1984, pp. 27-28)

These matters are mentioned below in no particular order. While some sort of logical order could be reconstructed, they emerged as issues to me more or less concurrently and gradually converged as several clusters of questions that led to the present study.

1) There are strong but disparate views of science and its significance

One stimulus for the present thesis was the strong and increasing societal interest in science, often together with technology, and in education, specifically science education. Many authors have characterised science in the twentieth century as a dominant influence in western societies, and an emerging force in non-western cultures. Scientific thought has been a significant theme in the history of Western European culture (Tarnas 1991) but the latter half of the twentieth century has seen great changes in science and in speculation about the nature of science and its role in society. Just one area of this interest has been the inextricable links between science and technological and economic developments, which have brought its influence to the attention of many sectors of contemporary industrialised societies (Ravetz 1971; Toffler 1981; Ziman 1984).
Ironically, increasing public interest in science is accompanied by popular perceptions that are inadequate and obsolete. The public hold powerful, although mixed, images of science that are well documented in the literature (Edge 1995; Lewenstein 1995; Wynne 1995; Cozzens & Woodhouse 1995). Some images characterise science as essentially benevolent, other as malevolent, and some as neutral. Two Australian examples will suffice. Robyn Williams, presenter of *The Science Show*, broadcast nationally on radio by the Australian Broadcasting Corporation (ABC), sees science as powerful because it is enabling, and therefore a source of pride:

Both Sir Karl Popper and his admirer Sir Peter Medawar have celebrated the Open Society as one of the greatest ornaments of modern democracy. They put science at the very centre of this ornament: 'Mankind's [sic] greatest achievement’, says Medawar. The reason they do so is because of the splendid scientific tradition of free discussion, scepticism, the pursuit of truth and a truly international network of communication. (Williams 1987, p. 48)

The biologist Charles Birch has also characterised science and technology as powerful, but this power is somewhat foreboding:

The most powerful and disruptive forces of the twentieth century are science and technology. The world’s most pressing political, social and economic problems have their origin in science and technology. The population explosion, economic growth, pollution and environmental deterioration, the means of war, the limits to growth, disparities of wealth and urbanisation. (Birch 1976, 1980 p. 324)

Despite the differences between these views, they share a widely held belief that science has become a significant force in society. This belief underlies much of the rationale for science education in the school curriculum. For example, it formed part of the rhetoric for preparing future scientists and technologists, particularly dominant since the 1950s and 1960s, and for public science literacy that became popular in the 1970s and 1980s. Various curriculum stakeholders still articulate these rhetorics today.

Such powerful but mixed images of science are significant for school science education. First, these images imply that science is worthwhile learning. Secondly, different views of science imply different curriculum experiences, as we will see.
2) *The increasingly utilitarian views of science and science education*

In the closing decades of the twentieth century, the value of both science and education have if anything been judged more instrumentally, especially by governments and industry. In the 1980s and 1990s, Australia, Great Britain, the USA and some other countries pursued public policies that were strongly influenced by instrumentalist economic considerations that gave market forces greater prominence in determining a range of policies concerning both the private and public sectors. There has been increasing pressure on public and service sectors to be more efficient and accountable, for example as determined by education and science policies.

Thus school Science is one of several curriculum areas that has come under scrutiny for its capacity to serve national economic interests and, explicitly in some countries, security interests. Rhetorics such as *science literacy* became less central than rhetorics of *competitiveness, efficiency* and *accountability*. Interest in quantifying the behaviour and productivity of systems has led to a trend of management by objectives. There has been a corresponding rise in pressure on the curriculum to become more vocational and pragmatic (Ruby 1991). Skilbeck (1987) has argued that these changes challenge the values of a classic *liberal* education, the imputation being that such an education is somehow a 'luxury' that is out of place and perhaps not particularly relevant to a modern, enterprising and productive culture.

The people and institutions that comprise the science communities have also been subject to similar pressures. For example, 1989 saw both the Australian Government begin establishing a series of science research centres, and the Australian Minister for Science, Barry Jones, call for scientists to be more active in seeking sponsorships and funding grants. Research funds are decreasingly characterised by relatively independent control by universities and regular growth, and increasingly characterised by the goals of projects with fairly short projections and identifiable economic benefit. The value of so-called *pure science* is increasingly measured in terms of short- to medium-term economic return. The links between the rise of utilitarian values, an economic imperative and science and
technology are illustrated well by the then Minister for Education, Employment and Training urging Australians to make Australia 'the clever country' (Dawkins 1990), a theme since used widely.

Science education in these circumstances is under increasing scrutiny and pressure, and increasing changes in the direction and rate of change of policy. These pressures and policy changes have been linked expressly to technological development and economic prosperity. This presents both opportunities and risks. The present thesis seeks to inform decisions concerning these opportunities and risks.

3) **Effects of rapid change in science and society**

The accelerating rate of change, both recent and projected, in Western (and other) societies is well documented. It has widespread effects on, among other things, science and science education. Of particular concern in the present thesis is that these changes place pressure on cultural structures, traditions and individuals, and the increasing need for informed decision making. Some commentators have also commented on the effect of rapid change, especially rapid changes in technology and science, on the public perception of and attitudes towards science and technology. These perceptions and attitudes affect the ability of citizens to participate in contemporary, pluralistic, participative democracies, a theme pursued in the present thesis.

4) **Curriculum development in a contemporary pluralistic democracy**

The increasing pressure on curriculum development in contemporary pluralistic democracies like Australia is one of increasing pressure on several grounds, as we have mentioned. It is not just that there is increasing interest in education and science, but that this happens along with changes in values, economic conditions and the orientation to and provision of schooling. This complex of factors influenced the direction of this thesis.

First is the trend towards a more managerialist approach to education across Australia and in other western societies (Sharpe 1991). Thus, as we will discuss later, themes such
as equity in education lost their primacy to themes such as efficiency, accountability, diversity, choice and excellence. Curriculum policy, for example, focused increasingly on managerial issues rather than content, resourcing or pedagogy, except in the periodic debates on literacy and numeracy. Thus the late 1980s saw several changes to managing the process of curriculum development in NSW: the replacement of (notionally) school-based curriculum development with centrally-developed curriculum and school-based curriculum implementation; the replacement of sometimes protracted, widely consultative curriculum development with centralised, ‘fast track’ curriculum development; and the shift of education policy decisions from the state Department of Education to the government (through the Minister) and the statutory education board (Board of Studies). An Australian example is the mapping of the curriculum, including science, in each education system in Australia with a view to determining commonalities and later exploring national curriculum guidelines. This commenced in 1988 under the aegis of the Australian Education Council (AEC), a council of federal, state and territorial ministers of education (Fensham 1995). As mentioned above, these trends were not confined to Australia: a relevant example is the introduction of the National Curriculum under the conservative government in Great Britain during the 1980s which served as a model for change for curriculum development in NSW. The AEC and British examples are instances of top-down approaches to curriculum development, which in both cases resulted from narrow consultative bases and in the latter became legislated.

Second is the changing perception of the curriculum and its role in a pluralistic democracy. This applies particularly to the views of policy makers and their use of the curriculum and other means of achieving changes in education. Again, the rhetoric involves less attention to curriculum content, and more to strategies like directing resources, restructuring management and mass testing. However, measures such as these can affect the nature of the curriculum, including the science curriculum, as we shall see in the concluding chapter.

Third is the legitimacy of the school curriculum. The combined effect of the changes, above, has been to greatly reduce open and public discussion of curricula as they are
developed. This can affect the legitimacy of a curriculum in a pluralist democracy, not just in the sense of being lawful, but being authorised or justified by following established practices and standards (The Macquarie Dictionary); that is, that legitimate interests are served. This is important: if a sufficiently influential fraction of curriculum stakeholders dismiss a curriculum as misdirected, perhaps because of inappropriate political or ideological pressures, then the community at large will come to distrust the curriculum too. Recent concerns by the Australian public over literacy and numeracy standards exemplify this point. Walker (1991) has argued that rapid social change necessitates devising processes to ensure that interests regarded by the society as legitimate have a voice in education policy:

[I]t is not possible in practice to separate questions of aims and procedures, of content and methods (and therefore) we have before us, in a time of rapid and extensive social change, a task of devising procedures which will ensure that legitimate interests are duly represented in education policy-making. (Walker 1991, p. 107)

The question of the legitimacy of the curriculum is central to the concerns of the present thesis. Questions concerning the education of the mass of school children, the mass of the future citizenry, are fundamentally tied up with the nature of society and preferred states of society. My own value preference is that the curriculum reflect broad and enduring value preferences: broadly based both in content and in community support, and enduring so that the maximum benefit of school education is felt by citizens in an increasingly changing society. A direct implication is that ideological or political enthusiasms must be measured against criteria of being well-argued and strongly substantiated. That is, the content of the science curriculum must be strongly substantiated and reflect the legitimate interests of as many curriculum stakeholders as possible.

Fourth is the changing role of curriculum stakeholders, where stakeholders are defined as ‘any group or individual who is affected by or who can affect the future of the organisation’ (Bryson 1988, as quoted and adopted by Fasano 1991, p. 122). The education policy literature speaks increasingly about curriculum stakeholders, meaning groups and individuals in society who make some claim to having a say in the curriculum. Moreover, political shifts in many western democracies in the 1980s saw more stakeholder
groups and shifts in their relative influence (Fasano and Winder 1991). For the science curriculum and the present thesis, a significant issue is that these stakeholder groups often have differing views about the nature of science and what the nature of school Science should be.

Fifth is the responsibility for the specification of the science curriculum. In NSW this responsibility has long been held by statutory boards, currently a single Board of Studies, for the Minister in the Government. Syllabuses are developed by curriculum committees or writing teams of the Board. Thus in NSW there is statutory responsibility for setting the curriculum: that courses are to be taught ‘in accordance with any relevant guidelines developed by the Board and approved by the Minister’ (for primary) and ‘in accordance with a syllabus developed or endorsed by the Board and approved by the Minister’ (for secondary) (NSW Education Reform Act 1990, Part 3). In NSW at the time of writing, school education has been covered by, essentially, only four main pieces of legislation in just over one hundred years: the Public Instruction Act of 1880 with a number of amendments over the years; the Education Act of 1961; the Education and Public Instruction Act of 1987; and the Education Reform Act of 1990. There are three important points to be made here about this legislative history: none sets out the content of the curriculum, or how that content is to be determined apart from the Board(s); they become progressively more detailed and explicit; and they have been revised and repealed in shorter and shorter periods of time. The second and third reflect the increasingly political and managerialist nature of the NSW school curriculum in recent years. The first reflects a history of syllabuses being developed by committees of the respective boards, where the committee membership, like the board memberships, were both representative and expert.

It is this type of curriculum development process the present thesis seeks to inform.

5) Personal experiences of science curriculum development

I have been fortunate to have had experience in science curriculum development at school, regional, state (NSW) and national (Australian) levels. However, I found the quality of decision making disappointing because the writing of curriculum did not always
reflect the optimum synthesis of several fields of knowledge and expertise. Curriculum writing and advisory committees depend on a blending or diffusion of ideas as the discussions lead to a consensus of some sort. Diffusion between such fields as science, curriculum, policy and pedagogy is a complex process and the extent to which it can be described as an entirely rational process is questionable. Such a process requires not only the specific expertise of the participants but knowledge of other possibilities, other ways of doing things.

Four aspects of this process are noteworthy here. First, in practice the optimum expertise was lacking: stakeholder representation typically arose from expressions of interest rather than securing the best person for the job. Secondly, the collected expertise did not necessarily equate with a coherent expertise: little and often no time was given to sharing the detail of various points of view. Thirdly, long-standing processes of widely consultative curriculum development gave way to ‘fast track’ curriculum development, as part of the rhetoric for increased efficiency and accountability. The accelerated development process placed additional strain on informed decision making. Fourthly, there is a case to be made that curriculum writers operate, if not in a theoretical vacuum, then in a theoretical hinterland. Certainly there did not seem to be a structured view of how various scientific, metascientific and science education research can be synthesised, which to continue the metaphor may be a meta-theoretical vacuum. A heartening exception at the time of writing is the revision of the NSW Science 7-10 syllabus, for which the Board of Studies hosted a symposium of curriculum stakeholders and at which various theoretical positions were put. Even here, though, the subsequent development process has been carried out by a syllabus writing group whose efforts have been disseminated infrequently and to limited audiences with short times for feedback. Fifthly, these problems are compounded when the product of such committee work is finally submitted for executive approval, in the case of NSW to the Board of Studies, and sometimes to the Minister. It is even less clear how those vested with the power of approving syllabuses, such as governmental ministers or senior bureaucrats, will possess the multifaceted expertise that syllabus writing committees should have.
Informed decision making can be promoted by research and theorising that draws upon all relevant fields. This thesis aims to contribute to such theorising and so inform curriculum development in this context.

6) **Personal experiences of science in public forums**

A second set of relevant personal experiences were public meetings I attended that involved scientific matters, such as siting a rubbish tip in a residential area, protests over the clear felling of native forests for woodchips, and closing a local hospital. Concerns about these meetings included lack of concern for verifiable information and the justification of claims; poor procedures for clarifying and analysing issues, and harnessing available expertise; and several well educated and knowledgeable people speaking beyond their authority and/or falsely. Further, I found that relevant scientific arguments and public policy were frequently difficult to check.

These raise several issues. One is the juxtaposition of the right in a pluralistic democracy for personal expression of a point of view, with the need in such a society for informed decision making. Another is that various points of view are not necessarily equivalent: some may claim scientific support while others do not; sometimes conflicting views both claim scientific support; sometimes scientifically supported claims have to be balanced with other, legitimate matters such as cost and employment implications. There are considerable literatures that deal with the public understanding of science, science controversies and public disputes (Wynne 1995; Nelkin 1995; Martin and Richards 1995), some aspects of which we will pursue later in the thesis.

These were personally compelling reasons to argue for changes in school Science to prepare people to take a meaningful part in decision making in personal and social situations. School Science could be useful in at least two ways here: useful in providing familiarity with and access to relevant knowledge, and useful in developing general, transferable skills in thinking and problem solving. However, there are significant questions about school Science. Why does school Science not prepare people to contribute to issues in more meaningful and constructive ways? It would seem that school Science is
somehow deficient because it does not enable most school students in this way: is this so? Are there other ways to conceptualise science for school education? If so, what might they be like?

7) **Personal experiences of science teaching**

The third set of relevant personal experiences was my contribution as a science teacher to my students' ability to deal with such issues. Consistent with research findings (Matthews 1994), only a portion of the most able students continued their school Science studies at a level that supported further study beyond the time when Science ceased to be compulsory (Year 10 in NSW), and most other students, including many able students, did not continue. Very few students of any ability showed a capacity or propensity to apply science to real contexts, which was unsurprising as the curriculum did not encourage this. These impressions were reinforced in visits to many schools during a stint as a science consultant. Thus my personal view was that school Science education made little lasting impact on the lives of students. This is a travesty in an increasingly scientific society.

8) **Research interest**

Another stimulus to the present thesis was the relatively small but growing degree of research interest in the nature of school science. This is discussed in some detail in the literature review chapter, but it needs mentioning here because of its formative role in the present thesis:

Roberts' emphases, Aikenhead's categories and other dissections of purpose and content demonstrate the richness of science as a human activity, and hence of its potential to provide meaningful content for all students to learn at school and, indeed, for the enrichment of the lives of all citizens. A classification of curriculum content like the commonly used *knowledge, skills and attitudes* is both too simple and too abstract to do justice to this richness in science. The simplicity of this classification pushes into its three categories aspects of the human exploration of nature that are epistemologically different. Its abstractness divorces science content from the dynamic and human situations of its origins and its learning. It is now time to replace, in curriculum thinking and planning for science, this unhelpful and oversimplified trilogy for the content worth learning. New typologies for describing science content are needed, and those that are emerging need to be encouraged in the debates about science for the school curriculum. Because of the complexity of science ... no typology will be ideal or even pragmatically the
neatest. Rather, some will be more helpful and useful than others, depending on the context or the stage of debate that the teachers and curriculum decision makers are in. (Fensham, Gunstone & White 1994, p. 3)

It would be difficult to argue that personal experiences or social developments alone would have led to the present thesis, because from the outset the metascientific, science education and curriculum literatures influenced the direction of my thinking and stimulated particular clusters of questions. These literatures report research that suggests links between the nature of science presented in the curriculum and several factors: poor student engagement with science, the public understanding of science, the resolution of science-based controversies in the community, and the education of scientists and technologists who are able to address the expanding and changing nature of science and technology and who are able to articulate their findings in debates that include economic, political, social and ethical dimensions. It greatly concerned me, and still does, that there are significant mismatches between these different literatures, and between the literatures and the enacted science curriculum. For example, there is a burgeoning literature on children’s construction of knowledge in science, and fields of literature that deal with the public understanding of science, and with philosophical, sociological and historical dimensions and understandings of science. However, I found little of any of this implemented as I visited and corresponded with schools, and little mention in the curriculum and education policy literatures. These impressions were confirmed repeatedly as I researched the present thesis and, with a few encouraging exceptions, remain.

9) Assumptions about the science curriculum

Finally there are some assumptions, usually implicit, about the school science curriculum that this thesis seeks to address:

a) school Science should be (mandatory) in the curriculum;

b) school Science should cover broadly the same content and be presented in the ways that it has done traditionally;

c) school Science should reflect or characterise science; and

d) school Science has traditionally reflected or characterised science.
We will take these in order.

a) **The premise that school Science should be (mandatory) in the curriculum**

   This thesis will argue strongly that science should be part of the general school curriculum, and that it should be mandatory for most school years at least. The concern is, however, that what is usually mandatory is a poor characterisation of science that ill suits the personal enrichment of students, the necessary science education for future citizens and the grounding for future scientists and technology. The argument pursued by this thesis is therefore that being mandatory is insufficient, and a robustly grounded school Science is part of the solution.

b) **The premise that school Science should cover broadly the same content and be presented in the ways that it has done traditionally**

   This premise is flawed. First, it is uncritical of traditional school science education despite criticisms on many grounds, as discussed in later chapters. The presumption that science deserves a mandatory place in the school curriculum seems to engender or at least reinforce other assumptions about the preferred content and delivery of the Science curriculum. This may, of course, arise simply through familiarity. Fensham has noted that many teachers are more hesitant and comfortable with the traditional types of elitist curricula for which their own socialisation in science has equipped them. (Fensham 1992, p. 798)

Hacker (1984) made a similar point about the relative failure of the Australian Science Education Project (ASEP) materials, which are integrated, student centred and organised around topics of student interest rather than subject tradition. Hacker found that the teaching styles required by the ASEP materials did not match the preferred teaching styles of most science teachers, and, further, that the teachers could not or would not change to meet the requirements of the curriculum materials. Teacher comfort or familiarity was a factor in revising NSW syllabuses also, where the very open-ended, student-centred approaches in the 1980 *Investigating Science K-6* policy and the 1972 *Science 7-10* syllabus were not widely endorsed by teachers. The subsequent 1990 *Science and Technology K-6* syllabus
and 1985 *Science 7-10* syllabus gave more structure and suggestions of explicitly *science* content, a trend continued in the 7-10 syllabus being developed at the time of writing.

Secondly, this premise ignores changes that have taken place in society, in education and science education in particular, and in understandings of science - metascientific understandings. Just one example is that new groups of learners are a significant element in the context of science curricula. Science curricula had, almost traditionally, been written for the minority of students who are most academically able. The trend in western-style democracies, from the 1970s and into the 1990s, has been for secondary education to become more widely available and accessible:

> The presence of these much greater and more socially representative numbers of students in the final years of secondary schooling, when science education has had its clearest definition and purpose, has meant that very new curriculum questions are being asked of science. Curricula that were designed for the preparation of future professionals have not proven attractive or appropriate for students who are not likely to enter such professions. On the other hand, that the majority of students should cease to study the sciences in their last two or three years at school is also an inadequate response to the importance now claimed for science. (Fensham 1992, p. 795)

The nature and purpose of a curriculum for the mass of school students is a significant, if not central, motivating concern of the present thesis. What are the needs of these students? This thesis will argue that a more robust and multidimensional characterisation of science can help to address this issue. More central, however, is the matter of changing metascientific views: this thesis will argue that this alone is sufficient to reject the premise that the content of the science curriculum should remain primarily as it was, and is.

Thirdly, this premise does not seek alternatives to traditional science curricula. The syllabus revisions mentioned above were in part a reaction to a perception that 1970s and 1980s curriculum development gave more emphasis to processes than to knowledge content. That is, that the *process versus content* debate swung too far away from requiring that students ‘know’ their subject. By implication there is a criticism that students should ‘know’ more science - ‘know’ their subject - rather than merely ‘do’ activities. This raises several issues: the extent to which policy pressures for accountability and efficiency drive the actual curriculum content through large-scale testing of students; whether *knowing versus doing* is a false dichotomy, and if so what a better analytical structure might be; and
just what it is that students should know or do - what does a close examination of the metascientific literature suggest that school children should learn? This thesis therefore seeks to delineate what the metascientific literature has to say that is useful to the school Science curriculum, and in so doing, to clarify debates about science learning outcomes, and by implication, what tests should test, and so forth.

c) The premise that school Science should reflect or characterise science

The present thesis will argue, as others have done, that, to the extent school Science reflects science, it should do so as authentically as possible. Further, it will show how this can be done. We have already alluded to the scant attention paid to specifying or clarifying the nature of science in the school curriculum: this situation undermines the justification of science in the school curriculum. This lack of specification may indicate assumptions on the part of legislators, at least, and possibly those who prepare the legislation and make advice on policy, as to the benefits and preferred views of science in the curriculum. The lack of specification may also contribute to difficulties experienced by the planners, designers, implementers and evaluators of science curriculum in refining their field, since it is then that the details have to be clarified and agreed upon.

Calls for the school science curriculum to better reflect the nature of science arise in both the education and metascientific literatures (see chapter 2). This reflects something of the variety of curriculum stakeholders who share this view, even if they do not agree on precisely what should be done about it, or how this should be done. It does not, of course, reflect the views of all stakeholders equally: school teachers, students, parents and the mass media, for example, do not as a rule publish in scholarly journals, but their views are partly represented in some of the scholarly studies and analyses. Early thinking towards the present thesis led to a pilot study of the views of school science teachers. However, the results, though only tentative, added nothing beyond confirming studies of teacher views already published. Consequently, the research question was changed and the pilot study omitted from the present study. What the pilot did show was the need for some theoretical framework into which the views of disparate stakeholders could be accommodated and analysed, and about which there was very little in the literature. Hence the decision to
ground the analysis in the published, scholarly literature as an authoritative and appropriate source of views about the nature of science. This decision was informed by readings of both the education and metascientific literatures.

d) The premise that school Science has traditionally reflected or characterised science

It is useful to highlight the fact that science does exist in all school curricula addressed here and, as in the context of NSW and elsewhere, it is included in a particular form. This point is important because there can be a temptation to presume that a subject that has been there for a long time and seems always to be included in any 'core' of the curriculum has its place in the curriculum established a priori. As noted above, many authors have argued that traditional approaches to school Science characterise science inadequately. The present thesis provides an analysis that shows not only how this is so, but how this can be remedied.

The presumed correspondence between school Science and the field or discipline of science is a fundamental assumption about their natures, but one that, considering its significance, is rarely scrutinised. In presenting a subject called school Science, a school curriculum is conventionally presumed to characterise or portray what is widely recognised as the field of study, science. The rationale for the very inclusion of the subject, and for its content and approach, relies strongly on this assumption. The present thesis tests this assumption and finds that in many significant respects it is not warranted. In a technical sense this is not a necessary cause for concern, because education systems can, in this sense, simply decree what subjects will comprise the curriculum and what the nature of those subjects will be. After all, school systems must make many decisions about what should and should not be in the curriculum, taking account of factors that go well beyond the presumed nature of disciplines such as science. In that case there is a responsibility, in a pluralistic democracy, for the education system to make clear what the distinctions and correspondences between the discipline and the school subject are, and why they have been made:

Finally ... [we look] towards a way forward for science education which is more securely grounded in our current understandings both of the nature of scientific inquiry and of human knowledge acquisition. (Millar & Driver 1987, pp. 36-7)
Where the correspondence - the grounding - is not clear, the rationale for the form and scope of the subject is weakened. The present thesis extends this critique to argue that a robust characterisation of science is more meaningful and more empowering than traditional characterisations of science for the school curriculum.

The present thesis as a response to these issues

In brief, the present thesis seeks to address the above issues, and some others, by:

1) analysing contemporary thinking about science in a way that assists informed decision making in the development of the science curriculum;

2) making suggestions as to what could and should be done in representing this in the curriculum; and

3) proposing guidelines for curriculum development based on this study, and suggesting further research.

The notional audience for this thesis is science curriculum stakeholders: syllabus writing groups, academics, teacher and school system representatives, other interested groups and those in government departments and in government who will influence the development of science curriculum through their executive decisions.
Questions arising from these concerns

Out of the issues discussed above arise various questions, of which the present thesis is mainly concerned with one:

*How can the school science curriculum better characterise the nature of science?*

The cluster of questions contributing to this central question is summarised below in Figure 1.1. The present thesis addresses this question by first addressing the research question:

*How does the metascientific literature characterise science?*

The cluster of questions contributing to this central research question is summarised below in Figure 1.2.

Briefly, the rationale for these questions is as follows. The concerns discussed above lead to many possible questions, of which the contribution or worth of science education to students and to society chiefly occupied my mind. Again, there are several possible notions of this worth, such as its contribution to a liberal education, to scientific literacy, and to further studies and careers in science and technology. This thesis is not concerned with singling out for attention any particular rationale for science education, and accordingly accepts all such curriculum arguments. However, when it comes to identifying the factors of science education that contribute to this worth, such as teaching, learning, the nature of the subject, the curriculum design, and so forth, we select for attention mainly one of these: the nature of the subject. Thus, when it comes to addressing the question,

*What is the worth of science education for all students?,*

the present thesis interprets this as,

*What is it about the nature of science that makes science worthwhile for students to study?*

The rejoining question is,

*How can the school Science curriculum better reflect the nature of school science?*

This question is interpreted in two ways. One concerns the clarification of science curriculum content:

*What is the nature of science?*
Chapter 1: Introduction

The other, which also arises from the concerns discussed above, concerns part of the curriculum process that is linked to the nature of the subject:

**How can curriculum decisions about the nature of school Science be better informed?**

This complex question suggests several possible answers, of which the present thesis addresses the development of a more robust characterisation of science itself. This reflects the concern of the present thesis with solutions that, while complex in their argument, address the curriculum reality that curriculum stakeholders will need convincing arguments to contemplate suggestions for science curriculum reform. The solution to both of these questions that the present thesis addresses is to clarify the views given in the metascientific literature, being the literature containing the scholarly, refereed, publicly available analyses of science. This is framed by the central research question,

**How does the metascientific literature characterise science?**

The answer to this question is framed in the methodology discussion in chapter 3, presented in chapter 4, and developed in the six companion chapters and their introduction (chs 5 to 11), and in Appendix B. The curriculum implications of this analysis are pursued in the final chapter, chapter 12.

**Questions about the contribution of this research**

Finally, another cluster of questions concerns the contribution of the present thesis as a piece of research. It places this thesis within a field of research, discusses the methodologies employed and offers some comment about the contribution of this thesis to the field.

Pedagogical factors are not discussed because, although important for effective science education, they introduce another set of considerations that arise secondarily from the central question.
Figure 1.1:
A schema of questions\(^1\) leading to the central research question, ‘How can the school science curriculum better characterise the nature of science?’

What is the worth of science education for all students?

LIBERAL EDUCATION: Science education has intrinsic worth as part of a general education

EMPOWERMENT: Science education is preparation for scientific literacy

VOCATIONAL: Science education is preparation for further study in science

What are the factors of science education that contribute to this worth?

Teaching Learning The nature of the subject Curriculum design Other

What does the education literature have to say about the nature of school science?

What is it about the nature of science that makes it worthwhile for school study?

How can the school science curriculum better reflect the nature of science?

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\(^1\) Grey arrows represent possible pathways; black arrows represent pathways addressed by the present thesis.
Figure 1.2:
A schema of questions leading to the central research question, ‘How does the metascientific literature characterise science?’

How can the school science curriculum better reflect the nature of science?

What is the nature of science?

How can curriculum decisions about the nature of school science be better informed?

What do curriculum stakeholders think the nature of school science should be?

How does the metascientific literature characterise science?

What are the implications for the school science curriculum?

The questions in Figures 1.1 and 1.2 are consistent, and overlap significantly, with questions such as those identified by a group of US science curriculum stakeholders and reported by Shymansky and Kyle (1992). They included:

*Why has the broader cultural significance of science virtually been ignored?* …

*How have the natural sciences changed us?*
*How can we understand and assess these changes?* …

*What will students need to know to be scientifically literate?*
*What are the values, images, customs, beliefs, and practices associated with the teaching and learning of a reformed science curriculum?* …
How can the nature of science be used to inform instruction? …

How do we prepare all of today's youth for tomorrow's world? …

What ought a reformed science education offer learners and society? …

Which fundamental concepts ought to be integrated into the curriculum? …

Should science education ensure a scientifically and technologically oriented work force versus a scientific and technological literacy for all? …

What (whose knowledge) counts as a legitimate science education? (Shymansky and Kyle 1992, pp. 750-4)

The present thesis has something to say about each of these, and other, questions about the nature of school science identified by various groups of curriculum stakeholders.

Comments about reading this thesis

The size of the thesis

The research and thesis turned out to be considerably larger than first expected, but there are strong reasons for this. The central reason is that characterising science for the school curriculum, robustly and in a way that is compelling for curriculum stakeholders, proved to be far more difficult than first thought. There are three main contributing reasons for this. First, it was difficult to establish some interpretative order in views of science, which are diverse, complex and frequently contradictory. Second was the growing realisation, as the thesis progressed, that the multiple dimensions of characterisation it proposes are found in the representations of science encountered daily by school students and citizens: not just in scholarly literature (which they do not encounter daily), but in texts, media reports, documentaries, advertisements, cartoons and so forth. Third were the repeated experiences of presenting drafts of the thesis to seminars and meetings, and finding that its central task was taken very seriously and perceived omissions and biases were keenly contested. Striking a balance between depth and breadth, always a difficult task in a thesis such as this, had to be adjusted many times as curriculum stakeholders from many groups seized upon some point or other and argued strongly a particular point of view. This was compounded when considering one dimension at a time, which emphasises the need to consider the dimensions as an interactive set when characterising science. Thus
to some extent, the length and scope of the thesis, and the relative depth given to topics covered are products of the concerns of many dozens of curriculum stakeholders. There are other elements of science that could also have been discussed, but which in striking the balance of length and scope received passing or no mention.

As a final comment on the size of the thesis, the extended analysis of metascientific arguments is given in Appendix B: summaries only are given in the six companion chapters (6 to 11). It is hoped that this presentation makes clearer the application of the metascientific literature to the curriculum focus of the thesis, but that the reader will nonetheless use discussion in Appendix B to gain a more detailed understanding of the ways in which a multidimensional analysis assists in understanding arguments about the nature of science. Experience in presenting drafts of this thesis showed the strong interest and uneven familiarity mentioned above, a situation best redressed using an analytical framework as suggested here. Further, the very length emphasises the complexity, magnitude and significance of the task, and therefore the significance of the arguments presented in Appendix B.

Some stylistic notes

The nature of the analysis made certain stylistic demands, for reasons concerning the nature of the analysis and discussion, and for clarity.

First, there is a large number of quotations included in the text, and of a greater length, than is the case in many theses. This arises directly from the aim of showing how the analysis is well grounded in the literature.

Secondly, there is a mix of primary and secondary sources. This is because the present thesis is an example of curriculum theorising, whose notional audience will not be exclusively interested in the direct translation or quotation of, for example, Plato, Bacon or Einstein, but also in how particular arguments are deployed by subsequent writers.

Third is the matter of gendered language: while every attempt has been made to avoid it, the one exception must be in the many quotations. Many of these quotations contain gendered language, which is unsurprising given that they were written before any general
awareness of its deleterious effects. Avoiding gendered language proved difficult. To merely report on or paraphrase an author would in many cases weaken the thesis, which makes extensive use of direct quotations to strengthen its argument. After all, its central purpose is to ground a particular area of curriculum theorising in its literature. To make editorial changes to quotations at best reduces the authenticity of the quotes, and at worst makes the text, with its editorial insertions in square brackets, convoluted and hard to follow. The best solution was to note the first use in any quotation of a gendered expression as verbatim by the conventional insertion of the term *sic* in square brackets.

The fourth matter of style concerns marking quotations. This thesis makes considerable use of quotations because of its task. In a thesis of this type, the excessive use of quotation marks and, for quotes within quotes, double quotation marks, clutters the page and hinders reading. To avoid excessive use of quotation marks, this thesis adopts other conventions where possible: extended quotations are all set in different typeface and indented; terms being discussed, and emphasised terms, are set in *italic* typeface; and quotations in the text are set within single quotation marks.
Chapter 2

A REVIEW OF THE LITERATURE

The purpose and structure of this chapter

This chapter reviews the literature on which the present thesis is based. The relationship between the thesis and the literature is complex. Firstly, the present thesis, like any piece of research, must show that it is well grounded in its literature and advances the field as measured by that literature. Secondly, the data for both the semantic analysis of summary statements and the extended analysis of metascientific argument were collected from the literature. The thesis makes three types of argument: an argument that the nature of school Science should and can be better characterised; an argument that the metascientific literature characterises science in multiple dimensions; and an argument that the present thesis is a sound piece of curriculum theorising that advances its field. Therefore this review of the literature must include several literatures: educational, metascientific and research.

To do this, the present chapter is organised as follows:

1. educational issues from the literature;
2. metascientific issues from the literature; and
3. methodological issues from the literature.

1. Educational issues emerging from the literature

Calls for the school science curriculum to better reflect the nature of science arise in a variety of literatures, mainly in education and metascience. This is not a dominant theme in either field, but it is a long standing concern, found in a variety of forums, and is growing as measured by volume of publication.

1.1 The nature of school Science is a longstanding, small but growing part of science education research
The nature of school Science is a relatively small area of research interest compared with other areas in science education. For example, research into learning probably comprises the greatest interest, and especially in recent years, research into students' alternative frameworks: Pfundt and Duit have reported a growth from 2000, in the third (1991) edition of their bibliography, to around 3500 in the fourth (1994) edition (Pfundt & Duit 1994, p. vi). To put the present thesis in context further, a review of science and technology education by Fensham (1992) identified thirteen influences on the current state of science curriculum development, of which the nature of school science is central in only one. While not equally the subjects of research, the thirteen nonetheless indicate the scope of scholarly interest, and place the present discussion in a broader context of issues currently applying to science curriculum development:

1. historical and sociological analyses of the curriculum
2. evaluations of the 1950/1960s curricula
3. new groups of learners
4. measurement of educational achievement
5. international comparisons
6. political and economic comparisons
7. concerned science teachers
8. science educators and their research
9. academic scientists
10. theories of teaching and learning
11. philosophical and sociological views of classroom science
12. major social changes and international movements
13. technologies for learning.

Fensham's instructive review is recommended to the reader requiring the extra detail and fuller discussion on this list, and particularly the references to key papers and the extensive bibliography. His analysis, particularly of point 11, above, is included in the review below.
Although research interest in the nature of school Science is relatively small, there are nonetheless several indicators that a range of science curriculum stakeholders view it as significant. For convenience, we will consider these indicators as three main groups.

First, there have been calls over many years for improved understandings of the nature of science (Jenkins 1996), 'and in fact the nature of each individual science', in both school curriculum and wider contexts (Finley, Lawrenz & Heller 1992, p. 268). Calls for improving students' understandings of the nature of science, and their facility with it, are made on a number of grounds, which are discussed in section 2.2 below.

Secondly, the amount of interest is growing. Reviews of science education research point to recent growth in studies into the nature of science as part of science education (Finley, Lawrenz & Heller 1992; Feldman & Atkin 1993; Lederman, Gess-Newsome & Zeidler 1993; Fensham, Corrigan & Malcolm 1989; Matthews 1994). For example, the nature of school Science has become an identifiable strand of interest in science education research. In the intermittent series of reviews of science education literature given in the journal Science Education, the review of 1990 research established a category, The Nature of Science, and noted an apparent 'emerging interest in the history and philosophy of science and its applications to issues in science education' (Finley, Lawrenz & Heller 1992, p. 239). Matthews (1992, p. 9) has reported that a special issue of the journal Synthese, advertised in 1987, and other journal special issues, devoted to metascience and science education, gave rise to the First International Conference on History, Philosophy and Science Teaching at Florida State University in 1989. In turn, this gave rise in to the journal, Science and Education (full title, Science and Education: Contributions from History, Philosophy and Sociology of Science and Mathematics) in 1992, and the International History, Philosophy and Science Teaching Group, which has held subsequent international conferences.

Thirdly, a variety of stakeholders have called for further research into the nature of school Science (Finley, Lawrenz & Heller 1992; Feldman & Atkin 1993). That is, calls have been made across the spectrum of curriculum stakeholders, including: the science education, education, scientific and metascientific communities; academics from other
fields; education policy elites such as governments and school systems; politicians and
governments; media commentators; and others such as parent, industry, trade union and
teacher groups. This is reflected partially in the spread of scholarly literature used by the
present thesis: in addition to the dedicated journal *Science & Education* and dedicated
books, the present thesis has drawn on articles in international science education journals
of Science Education*), national science education journals (in Australia, *The Australian
Science Teachers Journal, Research in Science Education*), other education journals
(*Journal of Curriculum Studies, Educational Leadership*), journals from other fields (*Public
Understanding of Science*), and in general educational and metascientific books. It is
perhaps a sad reflection on the (declining) political ‘clout’ of education academics as
curriculum stakeholders that the state of science education is held to be in an especially
parlous state when concern is expressed by non-academics:

The crisis [in the state of science education] has led to recent calls from business
leaders, politicians, and educators, for the reform of science education. (Gruender & Tobin
1991, p. 2)

The present thesis is a response to each of these indicators. Its analysis seeks to:

- contribute to the science curriculum debate through a better informed
characterisation of science for the school curriculum;
- extend the scholarly understanding of the nature of school Science, both as
  presently and potentially enacted;
- provide a means of bringing together the diverse views of science curriculum
  stakeholders; and
- provide both a substantial piece of research on the nature of school Science,
  and a stimulus and signpost to further research and curriculum development.

1.2 Educational issues in the literature

As indicated above, a variety of sources identify a variety of educational issues that
relate to the nature of science. A list of these issue is given below to show this variety,
together with suggestions for further research. It should be clear to the reader that these issues are overlapping and not discrete; they represent different perspectives and are not intended to be logically discrete. However, they do represent the different foci of arguments given in the literature concerning science education.

1.2.1 Pressure for science curriculum reform

First are arguments that the science curriculum needs reforming, where a more robust characterisation of science is part of the solution. This overlaps with several categories of argument being addressed in the present section. The school curriculum comes under attack periodically; this is nothing new, and by the very nature of the school curriculum will no doubt continue to be the case in the future. However, the 1980s and 1990s saw substantial public disquiet over curricula in the school systems of most western countries, and in particular over the science and mathematics curricula (Bybee et al. 1991; Matthews 1994). These criticisms have come from across the spectrum of stakeholders - governments, parents, industry, trade unions, academics - with a corresponding range of responses, both suggested and enacted (Ruby 1991; Winder 1991). Calls for a more robust grounding of school Science represent only one among many of these responses prompted by curriculum criticisms, but it is a significant response made by some of the reports established for the express purpose of addressing these criticisms. Matthews (1994, chapters 2 and 3) lists a large number of reports that call for an understanding of the nature of science as part of science curriculum reform. They include: *Education for All American Youth* (National Educational Association 1944); *The Place of Science in the Education of the Consumer* (US, National Science Teachers Association (NSTA) 1945); *Training of Graduate Science Teachers* (British Association for Science Education (ASE) 1963); School Science Education for the 1970s (NSTA 1971); *Alternatives for Science Education* (ASE 1979); *A Nation at Risk* (US, National Commission on Excellence in Education 1983) and the more than three hundred reports and twenty bills before Congress that resulted from it; *Science in the National Curriculum* (UK, National Curriculum Council 1988, revised in 1991); *Project 2061: Science for All Americans* (American Association for the Advancement of Science
(AAAS) 1989); *Unifying the Goals of Science Education* (Canada, Alberta departmental guide to STS education 1990); *Project 2061: Benchmarks for Scientific Literacy* (AAAS 1993); and *The Science, Technology, Society Movement* (US, NSTA 1993).

There have been some parallels in the Australian context, although on a smaller scale and perhaps with less success. For example, the Dirks Report (1984), sponsored by the Australian Science Teachers Association (ASTA), made wideranging recommendations for the aims and design of the science curriculum K-12, including understandings of the nature of science and the ability to apply scientific knowledge and skills in real contexts. Likewise, the national discussion paper, *Science for Everybody? Towards a National Science Statement* (Curriculum Development Centre 1988), set widely ranging goals for the science curriculum that were based on some broad notions of the nature of science. However, that paper proved to be greater in scope than the National Science Profile that eventuated, and the more conservative political climate in the late 1980s and 1990s has meant that the school curriculum, likewise, has become more conservative. While conservatism is inherently neither a good nor a bad thing, for Fensham it meant defining the curriculum by terms like *accountability* rather than by *student interest* and *science for all*, which he sees as misguided and counter-productive:

> In terms of the statements of intended curricula for science in Australia’s schools, the progress that was being steadily made towards science for all would appear to have been severely arrested, and even reversed.
> We have gone backwards. Having been well ahead of the UK in our conceptualisation of school science for 30 years, we have been returned to the past, at least in the official curriculum ...
> We can only hope that, on the ground, the influence of the new [national curriculum] framework will be minimal. (Fensham 1995, p. 203)

The present thesis will argue that pressures for a more inclusive school Science curriculum are consistent with more comprehensive characterisations of science, and that the concern of traditional science curricula with limited conceptions of knowledge and activity established a distortion of science that needs to be redressed.

1.2.2 An appreciation of the nature of science is necessary for a robust understanding of science
Second are arguments that an appreciation of the nature of science is necessary for a robust understanding of science. This has been argued by many science educators over the years (Finley, Lawrence & Heller 1992, p. 268). It has also been argued from metascientists. For example, Matthews (1994) cites a variety of claims to show that historical and philosophical understandings of science are a great help, and indeed necessary, to develop a sound grasp of scientific knowledge and activities. Similarly, there have been many calls for science education to study science in its broader contexts (Newton 1988; Edge 1995). C. P. Snow’s famous *Two Cultures* lecture, that dealt with the communication gulf between the sciences and the arts, is cited often as an example of how a narrow, intellectual approach to science leaves scientists unaware of, and unable to deal with, broader issues of science. Further, many now argue that without these philosophical, historical, sociological and technological understandings, students are much less able to develop robust understandings of science knowledge and its interplay with scientific activities and other characteristics (Jenkins 1996). This argument is made often in conjunction with calls for improved scientific literacy.

1.2.3 *School Science should be authentic*

Third are claims about the nature of science: that (traditionally a single, undifferentiated) *authentic* science has particular, essential characteristics that should be reflected in school Science. For example, Martin, Kass and Brouwer (1990) have observed that there have been many calls for school Science to be *authentic* science, but argued that the diversity of views about what authentic science would be makes this a very difficult task:

Science teachers are being challenged to present science as it ‘really is’ rather than promote a mythic, textbook science. The call for developing scientific literacy or teaching real or authentic science appears in an increasing number of documents such as *A Nation at Risk* (National Commission of Excellence in Education 1983) along with the NSTA position statement *Science-Technology-Society: Science Education for the 1980s* (1982). (Martin, Kass & Brouwer 1990, p. 541)

Martin, Kass and Brouwer summarise several views of the nature of science, and conclude from this that the notion of authenticity is difficult to determine, being better used
as a goal to which the curriculum should aim, rather than as a criterion that is necessarily arbitrary:

In attempting to give meaning to the term ‘authentic’, science educators should deal with the rich diversity of meanings of the term authentic ... Rather than attempting to establish an authentic portrayal of science at a specific point in the student’s education it may be more useful to see authenticity as an asymptotic state toward which the curriculum is pointing.

While it is difficult to identify an ‘authentic’ view of science, the rich diversity of meaning inherent in the term authentic science could be used to identify those cases where a portrayal of science is unauthentic. A science education that is tending towards authenticity would be one that draws in as many relevant aspects of science as are appropriate at a given point in the student’s life. For the young student this may mean no more than allowing him or her the opportunity to explore the personal dimension of science and may imply that greater emphasis be placed on the development of an experiential basis rather than in the formal development of ‘scientific facts and ideas’. (Martin, Kass & Brouwer 1990, p. 552)

This much is entirely consistent with the present thesis, which can be taken as a response to, and extension of, it. Further, Martin, Kass and Brouwer proposed a number of aspects or dimensions of authentic science: methodology; epistemology; the distinction between what science ought to be and how it is; the personal character of science, like the motivations of scientists, and the arduousness and exhilaration of authentic scientific work; the public character of science, meaning the science statements in articles and texts; the historical contexts of science; the social contexts of science; science and technology; and the aims of science. This is encouraging as far as it goes, but it seems to leave more questions than it does answers. The discussion is not altogether clear: the discussion of the different aspects is too brief to explain them clearly and defend them against existing metascientific positions, and the above summary of the aspects differs slightly from other summaries such as by Finley, Lawrenz and Heller. What, therefore, are the aspects of authentic science, and how were they identified? What of other aspects also discussed, like the tacit knowledge, belief and commitment of scientists, and the criterion or principle of falsifiability? What of other metascientific issues? Are there other aspects? Can some of these aspects be grouped, and the number reduced? It is clear that Martin, Kass and Brouwer set a large task, which was their aim, and it is one that cannot be done justice in a single journal article, which they did not claim to do. However, the present thesis does set out to make this sort of analysis. As we will see, its method and characterisation differ, but the characterisation is consistent with, and can accommodate, Martin, Kass and Brouwer’s analysis.
Finley, Lawrenz and Heller, noting the difficulty in determining authentic science, point to other attempts that also seek this goal:

While the difficulties associated with determining what counts as authentic science are substantial, there are attempts to at least find the features of the nature of science about which most researchers would agree. For example, Cleminson [1990] has carefully examined the writing of several key historians and philosophers of science and concluded that there are five features upon which there is substantial agreement. In a modified form, these key features are: (a) Scientific knowledge is tentative and should never be equated with truth; (b) Observation alone cannot give rise to scientific knowledge in a simple inductivist manner because our observations are greatly influenced by our theories; (c) New knowledge in science is produced by creative acts of the imagination allied with the methods of scientific inquiry; (d) The acquisition of new scientific knowledge is problematic and previously held ideas are not given up easily; and (e) Scientists study a world of which they are a part, not a world from which they are separate (pp. 437-438). While these statements do not address all of the aspects of science provided by Martin, Kass and Brouwer, they illustrate the type of research that is needed to develop an acceptable characterisation of the nature of science. As Cleminson indicates, these analyses are necessary to establish an epistemological base for curriculum reform and encouraging because the ways in which the nature of science is now being described is consistent with our emerging views of how the knowledge of an individual student changes over time. (Finley, Lawrenz & Heller 1992, p. 269)

As before, Cleminson’s purpose and suggested characterisation is consistent with the purpose of the present thesis, but it is inadequate: it addresses only a few characteristics discussed in the literature, and it is more a list of agreed differences from the traditional, positivist view of science than a characterisation of science. Again, this is due partly to the limitations of the single journal article; the present thesis makes a far more thoroughgoing attempt.

More recently, Roth (1995) has produced a book, *Authentic Science*, whose length does allow for this detailed treatment. However, it is a report on his attempt as a teacher-researcher to ground an open-inquiry classroom in authentic practices, where that grounding is in a particular view of science. It does not attempt to give a broadly grounded characterisation of science for the Science curriculum, as Martin, Kass and Brouwer, and Cleminson, sought to show and the present thesis seeks to show. These are sound reasons for arguing that Roth’s claim of authenticity is weakly supported.
1.2.4 *An appreciation of the nature of science is necessary for a liberal education*

Fourth are arguments that an appreciation of the nature of science is necessary for its intrinsic worth, rather than for narrowly instrumentalist reasons. This is the argument for a liberal, or general, education:

The best preparation for an uncertain future is a sound, general education that engages the present interest of learners. (Skilbeck 1984, p. 127)

The liberal education tradition opposes narrow, technocratic, and vocational conceptions of curriculum, a point made by Skilbeck in opposing the technocratic, instrumentalist curriculum models that were emerging as he wrote and that became very influential in western education systems into the 1990s. We will return to this theme in the concluding chapter, in the discussion of national political and economic goals and their pressures on the school Science curriculum. For the present, the liberal education argument has been used as a justification not only for the study of science, but for learning *about* science:

The present rapprochement between HPS and science education represents in part a renaissance of the long-marginalised liberal, or contextual, tradition of science education, a tradition contributed to in the last hundred years by scientists and educators such as Ernst Mach, Pierre Duhem, Alfred North Whitehead, Percy Nunn, James Conant, Joseph Schwab, Martin Wagenschein and Gerald Holton. At its most general level the liberal tradition in education embraces Aristotle’s delineation of truth, goodness, and beauty as the ideals that people ought to cultivate in their appropriate spheres of endeavour ... For a liberal, education is more than the preparation for work.

The liberal tradition is characterised by a number of educational commitments. One is that education entails the introduction of children to the best traditions of their culture, including the academic disciplines, in such a way that they both understand the subject discipline, and know something about the discipline - its methodology, assumptions, limitation, history and so forth. A second feature is that, as far as is possible and appropriate, the relations of particular subjects to each other, and their relation to the broader canvas of ethics, religion, culture, economics and politics should be acknowledged and investigated. The liberal tradition seeks to overcome fragmentation. Contributors to the liberal tradition believe that science taught from such a perspective, and informed by the history and philosophy of the subject, can engender understanding of nature, the appreciation of beauty in both nature and science, and the awareness of ethical issues unveiled by scientific knowledge and created by scientific practice. (Matthews 1994, pp. 1-2)

The same general argument is put by Edge (1995) and others in calling for school Science to embody the studies of the inter-relationships between science, technology and society, or science and technology studies (STS). In calling for understandings *about* science, these
arguments do not support narrow, traditional characterisations of science, calling instead for comprehensive and rigorous characterisations, which the present thesis terms robust. The present thesis also proposes such a characterisation for the school curriculum.

1.2.5 An appreciation of the nature of science is necessary for personal and social reasons

Fifth are arguments that an appreciation of the nature of science is necessary for personal and social reasons: personal knowledge; better public science literacy and the empowerment of citizens; more capable scientists and technologists; and national economic and security benefits.

Arguments for personal knowledge of the nature of science are similar to those for a liberal education, above, but they are made also in terms of the learning individual (Fensham 1995):

HPS can contribute to the fuller understanding of scientific subject matter - it can help to overcome the 'sea of meaninglessness’, as Joseph Novak once said, where formulae and equations are recited without knowledge of what they mean or to what they refer. (Matthews 1994, p. 7)

This is similar to the argument for a robust or rigorous understanding of science, above, but is included here to highlight that some arguments emphasise the benefit to the individual (personal knowledge) rather than the soundness of the knowledge (robust understanding).

Arguments for improved public science literacy also appeal to the notion of empowering citizens in the increasingly scientific and technological nature of western societies. Both of these goals have been used to argue for broader characterisations of science than provided by traditional school Science:

While educators agree that understanding issues in history and the nature of science and technology is critical to development of scientifically literate citizens, little, if any, instructional material is available for teacher use in this area. Moreover, most curriculum guides do not require teaching of the history and nature of science and technology, and teachers are not well prepared in this area. In the classroom, a laboratory or hands-on approach is often used to represent the nature of science and vignettes of scientists to represent the history of science. Nowhere is the student likely to encounter a cohesive view of the ways in which the intellectual development of the sciences and resolution of problems by technology shaped history and were in turn shaped by it. No conceptual framework that describes teaching and learning strategies that would more accurately reflect key themes in the history and nature of science and technology is available to guide improvements.
A place to begin is with the clarification of scientific and technological literacy. We propose the following major categories of understanding:

1. The scientifically literate person understands the nature of modern science, the nature of scientific explanation, and the limits and possibilities of science.
2. The technologically literate person understands the nature of technology, the nature of technological solutions to human problems and the limitations and possibilities of technology.
3. The scientifically and technologically literate person understands that the natures of science and technology as well as their interrelationships have changed over time.
4. The scientifically and technologically literate person understands that science and technology are products of the cultures within which they develop.
5. The scientifically and technologically literate person understands that the roles and effects of science and technology have differed in different cultures and in different groups within these cultures.
6. The scientifically and technologically literate person understands that technology and science are human activities that have creative, affective, and ethical dimensions.
7. The scientifically and technologically literate person bases decisions on scientific and technological knowledge and processes. (Bybee et al 1991, p. 150)

These issues and scientific literacy are addressed specifically by the present thesis in the concluding chapter.

Arguments for more capable scientists and technologists, and those for national economic and security benefits, are linked often but not always; both sets of argument appeal to a variety of factors, depending on who is making the argument. Thus some argue simply for making the existing science curriculum more rigorous (eg, Gross & Levitt 1994), although the nature of this rigour is often not specified, while others (eg, Fensham 1992; Matthews 1994) argue for making clear the historical and philosophical underpinnings of science:

The second response [to preparing future scientists and technologists] I will call the ‘critical’ or ‘self-awareness’ approach. This starts from the assumption that what young scientists most need (as, indeed, do we all, desperately) is ... some critical understanding of the nature of the situation into which they are being propelled, so that they can work out what is happening to them before it is too late and so allow them (at least in principle) to retain some control over their fate. You cannot ‘resist temptation’ unless you are able to recognise it for what it is. You cannot make rational choices of your course of future action without an understanding of this kind, and also a reflexive self-awareness of your own strengths and weaknesses, skills and aptitudes, inclinations and preferences, values and feelings, and so on. You cannot ‘exert willpower’ without such preconditions.

Applying this principle to science education, the ‘critical’ approach implies teaching material about science, its institutionalisation and social structure, its values and practices, so as to stress ideas about its social nature and its relationship with other social institutions ... (Edge 1995, p. 14; emphasis in original)
Despite the range of suggested solutions, there seems to be a shared assumption across some curriculum stakeholders that the effectiveness of the science curriculum is linked to these national failings and, therefore, to their desired improvements:

In our age of technological application and advancement, when business and industry have difficulty recruiting employees with the necessary knowledge of science and mathematics, few can doubt that the crisis in science education is a real one.

The crisis has led to recent calls from business leaders, politicians, and educators, for the reform of science education. In the US, such calls for reform have been fuelled by a decline in the economic viability of the country, and its failure to compete economically with countries such as Japan has been linked by some to a decline in the scientific literacy of high school graduates. (Gruender and Tobin 1991, p. 2)

This issue, and the appeals to rigour, noted above, are taken up in the concluding chapter.

1.2.6 An appreciation of the nature of science is necessary to engage students

Sixth are arguments that an appreciation of the nature of science is necessary as a solution to the declining interest, achievement and participation in science courses. Statistics detailing this low level of student engagement are a matter for widespread concern in recent science education literature, as in this review:

[D]isturbingly, students and teachers are deserting science.

This flight from the science classroom by both teachers and students has been depressingly well documented. In the US in the mid-1980s it was estimated that each year 600 science graduates entered the teaching profession whilst 8,000 left it (Mayer 1987). In 1986, 7,100 US high schools had no course in physics, and 4,200 had no course in chemistry (Mayer 1987). In 1990 only four states required the three years of basic science recommended by the sobering 1983 report *A Nation at Risk*, the rest allowed high school graduation with only two years science (Beardsley 1992, p. 80). Irrespective of years required, seventy percent of all school students drop science at the first available opportunity - which is one reason why in 1986 less than one in five high school graduates had studied any physics. In 1991 the Carnegie Commission on Science, Technology and Government warned that the failings of science education were so great that they posed a 'chronic and serious threat to our nation's future' (Beardsley 1992, p. 79). In the UK, recent reports of the National Commission on Education and the Royal Society have both documented similar trends. One commentator has said that 'wherever you look, students are turning away from science. Those that go to university are often of a frighteningly low calibre' (Bown 1993, p. 12). In Australia in 1989 science education programs had the lowest entrance requirement of all university degrees. (Matthews 1994, p. xiv).

A greater appreciation of the nature of science seems one of the few positive prospects suggested for this problem:
HPS can humanise the science and connect them to personal, ethical, cultural and political concerns. There is evidence that this makes science and engineering programs more attractive to many students, and particularly girls, who currently reject them. (Matthews 1994, p. 7)

1.2.7 A solution must be found for the difficulty in characterising the nature of science

Seventh are arguments that a solution must be found for the difficulty in characterising the nature of science for the school curriculum and, derivatively, for learning and teaching strategies and teacher education:

Several problems exist relative to teaching the history and nature of science and technology. First, there are no specific descriptions of scientific and technological literacy as these pertain to the history and nature of science and technology. Second, no conceptual framework exists that describes the teaching and learning strategies for the history and nature of science and technology. Third, teacher understanding of content and pedagogy is weak. Several authors (Russell 1981; Wagner 1983; Duschl 1985, 1988, 1989) have delineated these needs and problems. (Bybee et al 1991, p. 151)

The present thesis seeks to provide such a framework for teaching, learning and teacher understanding.

1.2.8 Present characterisations of science for the school curriculum are inadequate

Eighth are arguments that, although understanding the nature of science is included already in the goals and content of some school Science curricula, it is inadequate: it is characterised implicitly and incompletely, and in any case such good intentions in the formal, published curriculum are lost in the implementation. This is discussed at some length in the concluding chapter, but some indication of argument in the literature is necessary here. Thus a common view among science education researchers is that school Science is an inadequate and counter-productive characterisation of science. An example is the editorial to the 1991 special edition of Science Education that addressed the history and philosophy of science and science teaching:

Traditional approaches to science teaching and learning have focussed on students memorising facts about science and using algorithms to solve formulaic problems (Stake & Easley 1987; Tobin & Gallagher 1987). The teacher and the textbook have assumed the roles of the principal sources of knowledge, the paper and pencil tests have exerted a major driving force on the curriculum. Science is perceived to be a catalogue of truths about the universe: truths to be learned for later recall on a test. Evidence for these claims in the US is the number of reports and studies
which have identified serious shortcomings in elementary and secondary education (for example, those of the Carnegie Foundation, 1983; National Commission on Excellence in Education, 1983; Murnane & Raizen 1988; Weiss, 1987). The problems, however, are world-wide. (Gruender & Tobin 1991, p. 2)

Similar criticisms have been made of school Science in other education systems. Martin, Kass and Brouwer (1990, p. 541), for example, cite the 1975 Symonds Report of the Commission on Canadian Studies, that characterised school Science as ‘being taught as a body of knowledge and technique without any mention of its personal, social, or national relevance’. The characterisation proposed in the present thesis meets these criticisms by being thoroughly grounded in the metascientific literature.

1.2.9 The nature of school science arises from the curriculum focus or model, and changes as curriculum emphases change

Ninthly are arguments that the nature of science as presented in the school curriculum changes as the curriculum focus changes (Meyer 1977; Roberts 1982; McKenzie 1987). Developments in Australian science curricula roughly followed those in the US and the UK, with emphases shifting in the post-war years from unrelated facts, to unifying concepts, to processes, and then to values:

In the decade following that war, science courses were concerned primarily with the teaching of factual information illustrating the technological applications of scientific principles. The facts taught were often trivial and were rarely linked together by any criteria. Meyer (1977, p. 94) calls this the ‘grab bag era’ of science education.

Around 1955 this loose collection of facts began to be replaced by the ‘big ideas’ of science. Concepts and other content of science courses tended to be selected for their ability to contribute to the development of these ‘big ideas’. Meyer refers to this as breaking through the ‘content barrier’ and calls this the beginning of the ‘big ideas era’.

During this period there developed a curriculum reform movement characterised by an emphasis on the nature and structure of science and by the use of teaching strategies that involved students actively in learning - ‘inquiry approaches’ and ‘discovery learning’. Content continued to be selected for its capacity to contribute to ‘big ideas’. But it was now organised and used in such a way that it illustrated the processes of science. Meyer calls this breaking the ‘process barrier’ into the ‘inquiry era’. He dates this at 1965. The PSSC, Chemstudy and BSCS courses are exemplars of this from the United States, as are ASEP and JSSP in Australia.

Meyer postulated the existence of a ‘values barrier’ that began to be dented around 1975. The ‘era of the value judgement’ that lay beyond this barrier was characterised as emphasising the contribution of scientific knowledge and the processes of science to the amelioration of human and social problems. Meyer argued that the breakthrough of this barrier would effect a synthesis of content,
process and values to bring about a ‘confluence of understandings, attitudes, skills and insights to resolve conflicts between values’. (McKenzie 1987, pp. 160-2)

The present thesis will argue that curriculum emphases such as these in fact emphasise certain characteristics or dimensions of science at the expense of others. In passing it should be noted that there is evidence that shifts like these are complex and not at all clearly made at the classroom level: questions of content, process and values are still current and unresolved in the 1990s despite there having been major shifts in curriculum materials. This difference between the formal, published curriculum and the enacted curriculum is an ongoing issue in the curriculum literature. The more important point here, though, is that these particular shifts direct the attention of curriculum developers, teachers and students to different dimensions of the character of science. Thus the rise of process-oriented science curricula in the 1950s and 1960s was influenced by a view that science is a process of investigation. An example is Schwab’s argument that science is a process of inquiry or search for cause and effect, and therefore has curriculum implications, influenced the BSCS project (Fensham 1992, p. 792). Roberts’ (1982) argument that there are different science curriculum emphases means that there can be different emphases at different stages (Fensham 1994). The present thesis interprets this to mean different dimensions of science may be emphasised at different stages.

2. Metascientific sources and issues

2.1 Metascientific sources

The aim of the present thesis, to show that school Science can and should reflect better the nature of science, is addressed by theorising how the metascientific literature characterises science and how this could be better understood by science curriculum stakeholders. That is, the present thesis seeks to show how the school science curriculum can be grounded more robustly in the scholarly literature about science. Thus this review of the literature needs to clarify the metascientific literature as it applies to the present thesis.

In choosing the metascientific literature as the central source of metascientific views for the school curriculum, and in seeking mainstream views of science for the curriculum,
the present thesis made an a priori, if somewhat implicit, choice about initial literature sources. The metascientific literature is immense and growing, and no attempt could be made even to pretend that a comprehensive review is even possible. This is readily conceded by many authors (Martin, Kass & Brouwer 1990; Bynum, Browne & Porter (eds) 1983, Introduction; Jasanoff et al. (eds) 1995, pp. xi-xv; Oldroyd 1989, p. 1). In any event it would be a distraction from the purpose of the present thesis, which is not to tally the many views and their variants (an impossible and meaningless task) but to represent this variety. An attempt to review the field (a) is beyond the scope of this thesis, (b) is already provided in other texts, (c) would embody an analytical perspective that would itself be the subject of the present analysis, and (d) would not make explicit the characterisations proposed in the present thesis. In making use of the accounts in the literature, the present thesis selects accounts considered representative of widely, and some less widely, held views. The intention is to include sufficient detail from the literature to demonstrate the ways in which science is characterised, and show different stakeholders that the range of metascientific views can be discussed and compared within a common framework. It seeks neither to reproduce accounts already familiar to the reader acquainted with the literature nor advocate a partisan or pre-committed stand.

In this way it can place some significant and current views in some sort of context, and in turn develop a common conceptual framework within which this diversity can be placed. The main sources used for each field are given in chapter 3.

2.2 Metascientific issues

Discussion of metascientific issues takes up the greatest part of the present thesis, but some of the significant issues for the present thesis can be listed here:

a) Views about the nature of science are many, and establishing a particular view of science is a complex and difficult matter that can never be definitively concluded.

b) One source of difference is whether accounts of science should be normative (what science should be ideally), or descriptive (how science actually is
There is NO pp. 44-45 in original document
4. the comparison of statements and identification of key text units within them;
5. coding the key terms into semantic categories; and
6. links to further analysis and theorising.
1. Background and contextual influences

Parameters arising from the practical pretensions of this thesis

We noted in chapter 1 that the present thesis seeks to inform educational practice, specifically the development of a general, school science curriculum. This aim is a necessary restriction on the methodology and the range and type of outcomes to be considered. There are a large number of possible strategies and outcomes from analysing and theorising about the nature of science. Many of these are complex and require thorough familiarity with metascientific arguments usually removed from school science education. Therefore one criterion to be applied is that the solution be plausible in the context of curriculum issues. The curriculum and science education literatures contain many examples of curriculum initiatives that have failed or made little difference for various reasons (Fensham 1992). The metascientific literature contains many theories of science that may or may not be acceptable to a broad selection of curriculum stakeholders and, even if acceptable, have not been analysed for their curriculum implications in the manner presented in the present thesis. Scientists and metascientists as a group are familiar as stakeholders in the science curriculum, but their role and involvement have become clouded in recent years. Ongoing curriculum debates point to a need for their expertise to be shared more widely, and suggest that their role has been less than effective; and other stakeholders have become more influential, notably government and industry groups (Ruby 1991; Sharpe 1991).

In seeking to inform the development of science curriculum, then, the present thesis seeks to provide a framework (1) within which curriculum developers can place, compare and make informed judgements about the large and often disparate range of views about the nature of science, and (2) that is meaningful and plausible to all groups of stakeholders in curriculum development, and not just particular groups of stakeholders such as scientists and metascientists. The general aim is to produce a comprehensive and widely acceptable framework for the characterisation of science, which could encompass diverse views, which is appropriate in complexity to a mainstream school science curriculum.
The compatibility of such a framework with educational policy

The position taken in the introduction and rationale of this thesis was that curriculum debate in a pluralistic democracy should be informed and open. Given the discussion above, the question naturally arises whether an analysis such as proposed here meets this criterion. Also, the influence of government and education policy on the curriculum has been increasing and changing markedly in western countries from the mid-1980's (see, for example, contributions in Fasano & Winder (eds) 1991 and Collins (ed.) 1995). This has seen a shift in the power to make curriculum decisions, away from some traditional curriculum stakeholders such as teacher and professional educator groups, and towards other groups such as government, industry and unions. It has accompanied a shift of policy imperatives, for different curriculum emphases and faster curriculum development, that have restricted the contribution of public debate to the curriculum. Fensham has commented that, in applying diverse interests to education, it becomes likely, even probable, that the accommodation of one or more of these interests will lead to the exclusion of one or more others:

Recognition of this probability, unfortunately, is still quite rare in the reports and policies of the 1940s, as it was in the 1960s. Without it, some critical implications for science curriculum are likely to be missed in decision making for the current reforms in science education, just as they largely were in the development and implementations of the 1960s reforms. Hodgson (1987) has suggested that each proposal should be subjected to a scrutiny that reveals the underlying sociopolitical motivation of the interest groups. Whose views of science, whose interests, and whose views of society are being advanced? (Fensham 1992, p. 793)

Much of the science education literature from the 1980s has concerned, quite properly, student learning in science, notably the burgeoning literature on constructivism (Fensham 1992; Pfundt & Duit 1994; Wandersee, Mintzes & Novak 1994). Yet the radical interventions of conservative government policies on the curriculum make no mention of this. Debate at governmental level, and including the more recently influential stakeholders, appears far less concerned with the implications of learning theories than with the curriculum meeting broader needs such as micro economic reforms. A central concern of education debates at political and policy levels is the function of education, now widely interpreted as efficiency, accountability and curriculum content. We have
mentioned in the introduction, and will expand in the concluding chapter, that the drive for more responsive curriculum development meets political and administrative policy needs: short terms of political office, the costs of large scale curriculum projects, and changing political, economic and industrial goals have all been identified. The very long lead times of many earlier curriculum development projects at least partly legitimise the press for shorter development times. These are not the central concerns of much recent and current research in science education. The question that arises from this situation is whether an analysis designed to inform the nature of school Science would be useful in such a climate.

The answer to this question must be yes. First, the proposal of a framework that is grounded broadly in the scholarly literature provides a common setting for debating the diverse views of science in the curriculum. This would contribute positively to informed and open curriculum debate. Secondly, a framework grounded in the literature explicitly addresses the content of the curriculum, a concern that partly drives current changes in education policy. The present thesis is concerned also with the rationale for curriculum content, but its scope is broader and includes a strategic rationale for political debate in a pluralistic democracy. In a pointedly political exercise, of course, any piece of research can be excluded arbitrarily from consideration, as could the present thesis. Other than this, however, the present thesis will claim to be of use in determining the nature of science in the school curriculum regardless of how consultative are the development strategies. A characterisation grounded in the metascientific literature can be useful whether an education system seeks open debate over the school curriculum, or whether debate is closed by investing the change in government administrators or committees who report only to the government. Since the characterisation developed in this thesis is intended as a framework for (informed) debate, its credibility and usefulness are increased by accounting for a broader spectrum of views brought to the debate. The present analysis must therefore draw broadly on the metascientific literature to strengthen its credibility in an increasingly political and accountable process.
This concern with the effects of changes in government and education policy is an instance of the pragmatic criterion mentioned at the beginning of this chapter. It should not, of course, limit the scope of the thesis in the sense of focussing concern on a particular political or policy context. To the contrary, given the topic of the nature of science, the present thesis will argue that a plausible set of dimensions of characterisation can be discerned in the literature, and that accounting for a wide range of characterisations is likely to apply to characterisations of science to be made in the future.

The need to seek mainstream views

Arising from the rationale of this thesis, and its argument for students to be empowered as citizens in an increasingly scientific culture, is the question of how science is conceptualised in mainstream Australian culture. There will be at least some similarities, as we shall see, with the mainstream educational systems in other western cultures such as in Britain, western Europe and North America, and education systems in other countries similarly addressing science in the curriculum. Of course, the notion of a mainstream culture is problematic in many contexts, notably here the difficulties in meaningfully discussing notions like mainstream and a single, undifferentiated culture. However, the pragmatic criterion identified for the present analysis shifts the focus somewhat. As a piece of curriculum writing, the scope of the present thesis is restricted, arbitrarily and perhaps fluidly, to apply to the general curriculum in the mass school system, where there is an immediate need for utility and widespread acceptance. Thus it must at the same time acknowledge the cultural pluralism now widely recognised in these countries, which must be addressed by such a curriculum, and also that at some point in each school system a decision is made to adopt a particular science curriculum and it is this decision that the present thesis seeks to inform.

Sources of mainstream views

In this sense a mainstream view of science is taken here as that found in a diverse set of sources, mainly the scholarly 'metascientific' literature such as the history, philosophy, sociology and policy of science, but including the mass media, science
books and journals, general non-fiction including reference books, fiction, and curriculum documents. Use of such a diverse set as this could be problematic for the present thesis because it would expose the study to the criticism of having based some of the analysis on sources that were not credible to a scholarly critique, meaning a critique by those who have made an in-depth study of the issues, even if they argue from diverse perspectives. Clearly, a curriculum should be academically robust, at least sufficiently so to withstand such a critique. Accordingly, this study is based upon texts that would be acceptable to such a critique, with the aim of producing a framework within which any conceptions of science, mainstream or not, could be compared, analysed and debated. In this way debate about the science curriculum would be better informed concerning the nature of science. The present thesis argues that there are implications for the design and content of science curricula, curriculum and teaching resources, the training of teachers, and so on.

Criteria for this study

Given all the above, an account of science appropriate for a school science curriculum, as proposed in this thesis, must meet at least the following three criteria.

(1) It must be broadly based, and include a wide range of, and perspectives from, literature acceptable to a scholarly audience as defined above. Therefore it should base the discussion of the nature of school science on a well-grounded understanding of the ways in which science is characterised in the metascientific literature. It should accommodate the nature of science knowledge, which is large, expanding and subject to revision, and our understanding of the nature of knowledge itself. It should be appropriate for citizens in a multicultural and pluralistic society.

(2) It must be acceptable to the range of science curriculum stakeholders, but specifically curriculum writers and ultimately to teachers and students. This relates to parameters such as the overall complexity of the framework, the labels it uses for concepts and its appeal as a plausible and useful framework. Implicit in such a position is the claim that a theoretical framework is more likely to be adopted and used if it is more widely acceptable, especially to key stakeholders. The complexity of any framework
proposed is not central to the focus of the present thesis, since it introduces other factors such as the curriculum implementation strategies adopted by education systems. Nonetheless, it serves as a reminder to temper the complexities and subtleties that might arise from academic thoroughness with a consideration for what will be pragmatic and feasible, and meaningful to lay stakeholders.

(3) It must itself be open to further debate and development. It should not be restricted to present conceptions or to a particular conception that is disputed at a metascientific level, but instead be inclusive of the range of characterisations found in the literature and attempt to be so for future characterisations. The strategy of starting with the conventional, albeit diverse, views of established academic scholarship is not intended to restrict the findings to that set of views. Rather, it is to characterise science in a way acceptable to science curriculum stakeholders with expertise and scholarship in various characteristics of science. This is one step, but a significant one, in legitimising the science curriculum. It does not preclude other views from the curriculum, because ultimately such a decision is beyond the power of such stakeholders and lies with the formal education system and the government. If the results of the analysis are suitable, as it will be argued they are, they can also be applied to other, alternative views and the relative merits of different approaches can be discussed from within a common framework.

The relationship to existing characterisations of science in the curriculum

We have noted debate among science curriculum stakeholders about what sort of science should and could be in the school curriculum. The present thesis interprets this debate as concerning what the characterisation of science should be for the school curriculum, which does not a priori preclude present characterisations of science in the curriculum. We have noted also two tendencies in the ways science education writings characterise science: (1) to characterise science as knowledge, or processes or both, and (2) to take this as given or unquestioned. These two tendencies have been contested by Millar and Driver (1987), who argued that the so-called processes or activities of science are not characteristic of science particularly, but of clear thinking generally. They argued
instead that science is characterised by the purposes of this activity and the ends to which the knowledge is put; that is, science is characterised instead by its knowledge and purpose.

It is significant that in their theorising, Millar and Driver do not present a totally new construct, but instead theorise from the existing categories or dimensions of characterisation. As a matter of speculation, any number of alternative characterisations could have been proposed, although most of these would be novel to the science curriculum. For example it would be possible to propose a framework that used quite different organising concepts: familiar examples include the set who, what, where, why, when and how, and the set presage, process and product. A different kind of alternative would be to propose an extreme relativism that denied any privileged status for currently accepted frameworks, and thereby dispensed with any reductionist strategy resulting in categories of characterisation. Instead, Millar and Driver acknowledged the validity and usefulness of one of the traditional categories of characterisation (knowledge), and proposed that purpose replace the other (processes). Their proposal is therefore a development of the existing schema, familiar to science educators and science curriculum stakeholders. This would be more appealing to practitioners than replacing the familiar with a completely novel scheme, and its chances of successful implementation would accordingly be improved. The present thesis seeks to advance the field in a similar fashion, by developing existing schemas if possible.
2. The research questions and methodological overview

The central research question

The central goal identified in the discussion above is addressed in the present thesis by beginning with the research question,

What are the similarities and differences between the characterisations, or representations, of science in the summary statements in Figure A.1?

The proposed strategy is to categorise the data according to meaning and compare the categories. From the answers to this research question some judgements can then be made about the ways in which science is characterised in the scientific and metascientific literature, with a view to theorising about the characterisations found.

The general strategy

It would seem, therefore, that a strategy that began by allowing for the validity of the existing categories to be ascertained and the possibility of other categories to emerge would be more useful than starting completely afresh. The procedure adopted for the present study should allow for this possibility among other, more novel, possibilities. The grounded approach adopted in the present analysis is well suited to this criterion. It addresses the second criterion, above, concerning its acceptability to practitioners, but makes a radical reappraisal less likely.

Overview of the method of analysis adopted in this thesis

Given all the foregoing, the present thesis seeks to discern ways in which science is characterised in the metascientific literature and to propose a means by which these findings can be applied to the general school science curriculum. The strategy comprises three parts, as previewed on page 44.

1. The semantic analysis is an analysis of passages of text selected from the metascientific literature. The analysis constructs categories of meaning used to characterise science. The data for this analysis is given in Appendix A.1, the discussion is given below, as the remainder of this section, and the application of the analysis and generation of results are given in chapter 4.
2. The extended discussion and meta-analysis explicates the proposed categories and develops the argument that they are an interactive set of dimensions of characterisation. This is introduced in chapter 5 and developed in the set of companion chapters (chapters 6 to 11), using arguments from the metascientific literature analysed in Appendix B.

3. Finally is an argument applying the proposed characterisation of science to the curriculum, and its place as a piece of curriculum research. This is given in chapter 12.

The second and third parts are discussed later in section 6 of this chapter; we will confine our attention here to the first, which is the subject of the present chapter.

The semantic analysis

The first part, the semantic analysis, comprises three stages.

1.1 A broad range of text units, called summary statements, were selected from the literature: definitions of science, and statements that, while not necessarily written as comprehensive definitions, summarise all or part of an author’s conception of science. These are given in Figure A.1 (in Appendix A).

1.2 These summary statements were arranged into a common format, to facilitate comparison and the identification of key terms in them. This is given in Table A.1 (in Appendix A).

1.3 These key terms were coded into semantic categories following a grounded theory approach. This is given in Tables A.2 to A.11 of Appendix A. The results of this analysis, the indications of how science is characterised in the metascientific literature, then form the basis for the argument presented in the body of the thesis.

The remainder of this chapter comprises these three stages of textual analysis.

The purposes of textual analysis

In describing categories of textual content, the present study seeks to discern different meanings rather than compare the frequencies of text units. It is therefore
concerned with recording themes rather than word units. This represents one of three main purposes of analyses of textual content identified by Holsti (1969, pp. 42-3, with reference to Kerlinger 1964): (1) describing its characteristics (the purpose of this analysis), (2) making inferences about its causes, and (3) making inferences about its effects. The present analysis is more judgemental and subjective than a mechanical recording of word units to determine their frequency. This is both a strength and a weakness (Carney, 1972, pp. 46-7).

**Methods of textual analysis**

There are various ways of analysing text that suit various purposes and contexts (see Holsti 1969, Table 2-1). The present analysis concerns the meanings discerned within the summary statements in Figure A.1, i.e. it is a semantic analysis. Semantic analyses can be undertaken by methods from different fields, including logic, psychology, anthropology, literary criticism, communications science and linguistics. Within linguistics there are alternative approaches also, including logical relations, substitution, compatibility (collocation), distribution, synonymy, antonymy, hyponymy and others (Nida 1975, pp. 194-5). Considering the various methods available it is prudent not to be too doctrinaire in the present analysis, because different methods will yield different insights. It is therefore important to acknowledge that a particular approach, adopted for particular purposes, will produce particular results, as in the present thesis.

3. **Compilation of summary statements**

*The collection of data*

The data collected for analysis comprise passages of text, ranging from a single sentence to several paragraphs, from the metascientific literature. The metascientific literature is taken here to be the massive and growing corpus of work in reference books, texts and journals especially from fields such as science and the history, philosophy and sociology of science, and more generally from fields such as history, sociology and...
linguistics. These units of text are identified as suitable for the present analysis because they summarise the authors' view of science or some aspect of science. For the purposes of the present thesis, the text units are called summary statements. Some are explicit definitions of science, such as dictionary entries, while others are judged by their form and context to be equivalent to such a definition. The latter type are those judged to imply a definition or partial definition, such that they can be slightly reworded to make their definition more explicit without loss or alteration of meaning. Having established a collection of such summary statements it is then possible to draw a comparison to discern differences and similarities.

It may be objected at this point that a sentence or paragraph extracted from a monograph of several hundred pages invites taking quotations out of context and a specious interpretation. In answer to this concern, first, the sources of the data in Figure A.1 include many expected to be known to the reader with at least a passing familiarity with the metascientific literature: even if the actual quotation is not known, the reader would be able to form a judgement as to its veracity. The range and number of sources of the summary statements make it likely that any such reader will come across authors whose work is familiar. Most of the sources in Figure A.1 should be recognisably authoritative to such a reader. Secondly, the textual analysis is not the complete argument, but merely the means by which categories of characterisation are discerned. The arguments for the proposed categories, and their interpretation as dimensions, are made separately in Appendix B and summarised in the respective companion chapters.

Sources of summary statements

The first stage was locating and collecting the summary statements. Clearly, there is a great variety of theoretical positions, contexts and intended audiences in interpreting science in the metascientific literature, hence the need to meld various viewpoints as part of the rationale of the study. Theorists within of each of these fields exhibit a range of responses towards other viewpoints, which may be: accepted but not preferred; credible and have significance in other contexts; accepted as legitimately held by others but rejected in favour of another view; or directly opposed or rejected. This diversity of
view, both about science and about other metascientific views, may be surprising to the lay reader, but unsurprising to the reader with some familiarity of the field. In any case, this is the very issue that the present thesis seeks to address: it is all grist to the mill.

Similarly, in the context of developing science curriculum, the various stakeholders need not be expected to find other viewpoints credible or perhaps significant. For example, academic or industrially based scientists appear less likely to be concerned with the diversity of metascientific arguments that philosophers and sociologists of science would have appraised. Figure A.1 therefore includes entries diverse enough that each of these groups of stakeholders would find something plausible: general dictionaries and encyclopaedias; dictionaries and encyclopaedias of science, philosophy, philosophy of science and sociology of science; general, undergraduate-level texts in science, history of science, philosophy of science and sociology of science; and texts and articles identified through library searches of key words and prominent thinkers. In turn, many of these sources suggested texts and authors for further study that yielded summary statements. Further, having found certain texts well recommended in the literature, other texts by the same and other authors were canvassed for summary statements.

Selection of summary statements: credibility

Having found a sample of text potentially worth including, the second stage concerned the judgement of whether the example could be claimed to be frivolous or unacceptable to stakeholders with metascientific expertise. This implies criteria of academic credibility, rigour and depth, and raises questions of what standards and whose standards. Again, the types of sources listed above would satisfy most critics on these criteria. The metascientific literature comprises the published findings of established and recognised fields of scholarly research and theorising that is available for public scrutiny and, being peer-reviewed, has been subject to academic scrutiny as part of the publication process. Views about science expressed in the tabloid press, for example, would be of interest in shaping a science curriculum, but they should be the subject of the present analysis and not form part of the data from which the thesis was constructed. The sort of authority to which the tabloid press would appeal in making a thoroughly argued
characterisation of science, as distinct from a populist characterisation, is the sort of authority that the present thesis seeks to scrutinise. Of course, even within the metascientific literature, some views are broadly accepted as legitimate (even if not universally agreed with) and others only marginally accepted. Given the purpose in this study of addressing the mainstream school curriculum, it is legitimate to seek mainstream views of science.

This raises the question of what constitutes a mainstream view. There is no expectation that any one reader will find all the statements equally acceptable. Rather, the argument is that the summary statements (1) comprise an acceptable representation from the metascientific literature, (2) have each been subjected to a similar analysis, and (3) have been subjected to an acceptable analysis. The framework developed from this analysis could then be applied to characterisations that may not be acceptable to the metascientific community and would be a means of clarifying why such characterisations are judged as unacceptable. The intention is to clarify the ways in which science is characterised in the metascientific literature.

Accordingly, consideration was given to ensuring that the entries in Figure A.1 were acceptable as legitimate metascientific statements, even though it is recognised that for any one reader the diversity of views included will no doubt present a mixture of the academically acceptable, the disagreeable and the curious. It is important that the distinction is understood between the deliberate sampling of a wide range of views from the metascientific literature and the analysis of those views. It is hoped that the reader will agree that the analysis of his or her preferred statements is valid, even though he or she might not agree with all the other statements. By extrapolation, it should be clear that the analyses of these other statements are similarly valid, and that therefore the analysis proposed in this thesis applies broadly to the characterisation of science.
Selection of summary statements: form

As the collection of summary statements grew, it became apparent that they were all either explicit definitions of science, or approximated the form of defining or elaborating terms:

The grammar embodies a range of ways of defining or elaborating terms. The most familiar and probably the most frequently used is to define technical terms through an identifying relational clause. (Halliday & Martin 1993, p. 149)

Thus sentences were judged to be suitable as summary statements if, in a general sense, they defined or elaborated the term science. If the surrounding text was judged to be useful in providing additional meaning, then it was included also. More detail on grammatical considerations is given below.

Representativeness of the data

The third comment on selection concerns representativeness and the number of texts sampled. The sample is not a representative sample. It would be difficult enough to guarantee a representative sample of metascientific texts, but the interpretative nature of selecting text units as summary statements precludes any such notion. As a general statement, all quotes found by means of the search described above were included in Figure A.1. The present study seeks to discern categories of meaning and therefore not the relative numbers of particular viewpoints: it is concerned with the qualitative differences between different characterisations. Thus, while there would be no reason in principle to include two statements that are worded identically, we are not concerned with how many times a statement is found. For example, in the case of two dictionary entries the same statement was given twice, but was recorded only once for analysis. This is consistent with the analysis below, which creates categories of meaning by putting together terms with similar meanings. There is no significance in the order of the entries in Figure A.1, except for statements 95 and 96, which are included consecutively because they illustrate a shift in thinking between books with the same editor but separated in publication by over two decades.
4. The initial coding: comparison of statements and identification of key text within them

Options for coding or categorisation of terms

Since the research question seeks trends or patterns in the use of meanings, the next stage was to construct categories of similar meanings. Several options are available in the coding or categorisation of the terms collected (Miles & Huberman 1984, pp. 54-72). The first is to begin using a list of codes developed before the collection and analysis of data, in the manner of interview or observation schedules or checklists. The advantage of this option is that it can be set up to embody the conceptual framework, research questions, hypotheses, identified problems and variables identified by the researcher (Miles & Huberman 1984, p. 57). This approach is interpreted as a rigidly pre-determined schedule of categories and is not suited to the general grounded approach as in the present analysis.

A second option is to wait until the data are collected to see what categories can be identified. The advantage of this inductive approach, as discussed earlier, is that the data are less likely to be 'moulded', as it may be into pre-existing codes such as the first option uses, and the researcher is freer to seek alternative explanations. The problematic nature of induction in philosophy should be noted, in that there is disagreement about whether and how induction works. However, it is not problematic in the pragmatic sense proposed in the literature on grounded theorising, and certainly not as interpreted here, in which provisional speculations and revisions of interpretations are not only acknowledged but encouraged. (See the discussion below of theoretical sensitivity.) A third option represents a mid-point between the first two, which is to use categories or codes that are not specific to content and general enough to handle a variety of data and suggest further categorisation. This is more receptive to modification than using pre-existing codes but provides sufficient structure to help avoid the inconsistencies and retrospective adjustments that can result from an empirical, grounded approach.

The analysis presented here represents a combination of the second and third approaches. The initial coding used three general categories of grammar/syntax, as in the
third approach above. This coding was used simply as a technique for structuring the text units so that the key terms could be identified more clearly and consistently. The subsequent codings were used to create semantic categories. They began with the tentative identification of the traditional categories of characterisation (knowledge and processes), and continued to establish further categories (chapter 4). These codings draw on the techniques of grounded theory, as in the second approach, above.

**Beginning with 'core' meanings**

The initial stage of analysis was to identify 'essential' or 'core' meanings in the text units without distorting the data. It does not suit the purpose of this analysis to alter data, or use data selectively, to make the text units conform to pre-determined coding categories.

**Lay's procedure for analysis of formal definitions**

The basis of the present analysis was that of Lay (1982, pp. 45ff), who provided an analysis of formal definitions using a method of coding that meets the specifications given above. In Lay's method of analysis the subject of each statement is set against its predicate, and from the predicate the class of categorisation can be determined. From Lay's account, the subject of the sentence is identified as belonging to a class, and then distinguished from all other subjects. This is done by describing the term to be defined in terms of the *class* and the *differentiae*:

\[
\text{The term to be defined} = \text{the class} + \text{the differentiae}
\]

\[
\begin{align*}
\text{e.g.} & \quad \text{science} & \quad \text{is the investigation and analysis of natural phenomena} \\
\text{e.g.} & \quad \text{biology} & \quad \text{is the study or science of living organisms and vital processes}
\end{align*}
\]
Within this analysis, a formal definition must meet two criteria: (1) 'the subject does belong to the class and (2) the differentiae exclude all members of that class except the one being defined' (Lay 1982, p. 48). By the first criterion, the differentiae must not repeat terms from the class or subject being defined: *science is what is done in science labs* does not define, but merely repeats. By the second criterion, *science*, for example, would have to be distinguished from *technology*.

**Subjecting the summary statements to Lay’s analysis**

The initial analysis of the summary statements found in Figure A.1, using Lay’s framework, is given in Table A.1. Most entries fitted this framework because the subject is *science*. In other cases the original was reworked to make the subject *science*, so making the analysis clearer and more consistent:

- where the standard definition format is implied;
- where more than one definition is made or implied in the extract (in which case there is more than one subject, and the definitions of each of the extra subjects are included); and
- where the original text is a sentence with several relevant clauses.

Care was taken not to alter the original meaning. The original text is in any case available to allow the reader to check the interpretation. Simply dismembering the text can diminish the clarity of the original meaning and integrity of the text. In these cases, wording in square brackets [ ] was added to clarify the meaning. In cases where the original was reworked, as in summary statements 5, 6, 8, 9, 11 and 14, for example, a reworked version is indicated by the conjunction *or*. The version corresponding most to the original is given first.

Whether as originally worded or reworded, the word *science* is the subject in all examples as analysed. It is mostly used to denote a concept, but in a few examples it denotes a word or term (*Science is the term used to* ...), as in, for example, summary statements 1, 5, 14 and 80. This does not seem to make any difference, however. The examples of science as a term were interpreted in terms of science as the subject, and add nothing further.
In a few cases, science is described in terms of what it is not: it is distinct from either tradition or authority (summary statement 14), not just a collection of laws [or] a catalogue of facts (summary statement 15) and is not a technique; it is not a form of power; it is not even simply an accumulation of knowledge (summary statement 16). These appear to be intended to reflect a concern to counter some popular notions of science, and indeed is the substance of the article from which Feynman's quote (summary statement 6) is taken: that the terminology, for example, is just the labels and tools of science - necessary for, but not actually science itself. The classes set out in terms of not being something in fact are worded in two ways. Bronowski (summary statement 16) claims science is neither a technique nor a form of power. But a different wording is used by Bronowski for knowledge and by Einstein and Infeld for laws and facts: not just and not simply. Science is actually being described in terms of those qualities.

**Determining the classes: establishing subject, class and differentiae**

Where the structure of the text entry matched Lay's format or was easily reworked to be so, establishing the class and differentiae was unproblematic: the subject is explicitly part of the class. For example:

A1.9 Modern science is a search for understanding expressed in laws or principles of greatest generality and which are capable of experimental test.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Class</th>
<th>Differentiae</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modern science</td>
<td>is a search</td>
<td>• for understanding</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• expressed in laws or principles</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• of greatest generality</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• and which are capable of experimental test.</td>
</tr>
</tbody>
</table>

**Determining the classes: reworded examples**

Where possible the subject was taken to be the noun only, in order to reduce the text unit of the class to its essential meaning. Any qualifications of the noun, such as by a
clause or adjective, were taken to be qualifications of the class and therefore one of the differentiae. Using the same example:

\[
\begin{array}{|c|c|c|}
\hline
\text{Subject} & \text{Class} & \text{Differentiae} \\
\hline
[S]cience & \text{is a search} & \text{• for understanding} \\
& & \text{• expressed in laws or principles} \\
& & \text{• of greatest generality} \\
& & \text{• and which are capable of experimental test} \\
& & \text{• [as practised in modern times]} \\
\hline
\end{array}
\]

In some cases judgements were not so easily made, and determining the subject depended on the particular wording adopted for the text unit. In these cases the differentiae served not only as qualifications of the subject but also to 'mop-up' or save the remaining ideas in the original text. That is, the original data are preserved. Summary statement 4 is an example in which the core characterisation is made by several words:

\textit{A1.4 Science is a developing body of knowledge ...}

At face value there are several possible interpretations:

\[
\begin{array}{|c|c|c|}
\hline
\text{Subject} & \text{Class} & \text{Differentiae} \\
\hline
\text{Science} & \text{is a developing body of knowledge} & \text{• [which is] developing} \\
\text{or, science} & \text{is a ... body of knowledge} & \text{• body} \\
\text{or, science} & \text{is ... knowledge} & \text{• [which is] developing} \\
\text{or, science} & \text{is a ... body} & \text{• of knowledge} \\
& & \text{• [which is] developing} \\
\hline
\end{array}
\]

In this case, and in several others, the essential characterisation is \textit{body of knowledge}. Following the principle, above, of trying to reduce the Class to its essential term, the characteristic developing can be put aside into the differentiae, but the remainder could be interpreted as \textit{body of knowledge, or body (of knowledge), or (body of) knowledge}. This example was not clear, and so was entered twice, as \textit{body} and as \textit{knowledge}. 

Determining the differentiae

The differentiae are dealt with later. See below.

Setting out the subject, class and differentiae

For clarity, the first line of differentiae in Table A.1 (column three) are marked with a bullet (•) and subsequent lines are indented. The fourth (right-hand) column contains the key words from the analysis of each entry: the class in upper case letters and the key words from the differentiae in lower case. Using the same example:

<table>
<thead>
<tr>
<th>Subject</th>
<th>Class</th>
<th>Differentiae</th>
<th>Key words</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science</td>
<td>is a search</td>
<td>• for understanding</td>
<td>SEARCH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• expressed in laws or principles of greatest generality</td>
<td>• for understanding</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• which are capable of experimental test.</td>
<td>• laws or principles</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• [as practised in modern times]</td>
<td>• greatest generality</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• capable of experimental test</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• modern [times]</td>
</tr>
</tbody>
</table>

See Table A.1: An analysis of the summary statements of science given in Fig. A.1, which follows Lay’s (1982) method for analysing definitions.

5. The second coding: coding the key terms into semantic categories

The next stage of analysis was to seek regularities or patterns in the use of key words of classes in summary statements of science. This entailed a second process of establishing categories, this time on the basis of meaning. Judgements had to be made in establishing the categories into which the data are distributed. The greater subjectivity introduced in establishing these categories therefore had to be carefully identified and monitored. A common means of compensating for this subjectivity is by proliferating the number of categories, but this presents its own problems, including ending up with an unwieldy system (Holsti 1969, p. 98).
Grounded theorising

The overall methodology is an example of grounded theorising (Glaser & Strauss 1967; Glaser 1978; Strauss 1987; Strauss & Corbin 1990):

A grounded theory is one that is inductively derived from the study of the phenomenon it represents. That is, it is discovered, developed, and provisionally verified through systematic data collection and analysis of data pertaining to that phenomenon. Therefore, data collection, analysis, and theory stand in reciprocal relationship with each other. One does not begin with a theory, then prove it. Rather, one begins with an area of study and what is relevant to that area is allowed to emerge. (Strauss & Corbin 1990, p. 23)

That is, the present analysis is an attempt to derive some sort of construct or theory inductively from the data, where the data are the summary statements of science from the metascientific literature. The proposed analysis represents grounded theorising as proposed by Strauss and Corbin in the following respects. The summary statements given in Figure A.1 were subjected to a process of coding, beginning in Table A.1. Each was subjected to a semantic analysis, initially following the method proposed by Lay (1982) and described below, in which the subject is set against the predicate (Table A.1). Collection and coding of the data entailed developing the theoretical sensitivity necessary for grounded theorising, where theoretical sensitivity is

an awareness of the subtleties of meaning of data ... the attribute of having insight, the ability to give meaning to data, the capacity to understand, and capability to separate the pertinent from that which isn’t (Strauss & Corbin 1990, pp. 41-2).

The data are coded in Appendix A. They were coded into key words of subjects and predicates in Table A.1, are then coded and placed into categories, and the categories named (Tables A.2 to A.10). The six proposed categories of characterisation resulting from this analysis form the basis for, and are developed respectively, in Appendix B and the six companion chapters.

Minimal structure to this point

Lay’s approach, which had been used up to this point, imposes minimal structure on the coding of the data and is therefore a general coding system as described in the third option described by Miles and Huberman, above. The simplicity of the categories - subject, class and differentiae - and the fact that they address grammar and syntax in the
most general way, not the meaning content, means that they do not constrain the categorisation of meaning and a degree of 'grounded' theorising is possible.

**Possibilities for the categorisation of meaning**

Having collected data in the categories of class and differentiae, the question then arose as to the categorisation of meanings. The use of a complete and pre-determined set of categories has been discounted above as unsuitable to the present analysis. The use of general categories is possible, at least in principle, and two approaches are examined here.

**Lay's categorisation of cause**

The first is the continuation of Lay's method of analysis. Lay proposes further general categories to be used in the coding of the differentiae, which 'can include four characteristics or “causes” [following Aristotle's doctrine of four causes]:

- the *efficient* cause (what created the object or term),
- the *material* cause (what the object is made of),
- the *formal* cause (what the structure of the object is), and
- the *final* cause (what the function of the object is).' (Lay 1982, p. 48)

One or more of the causes may be used as appropriate. Admittedly, these are intended to apply to the differentiae and not the classes, but the method had been useful to this point in systematically segmenting sentences, and its full use would potentially have been useful.

**Halliday's categories of circumstance**

The second is a functional grammar approach (Halliday & Martin 1993; Halliday 1994). As with Lay's approach, this approach is based on the language structure rather than the semantic content. However, a functional grammar approach enables the categorisation of text units based on 'how the language is used' (Halliday 1994, p. xiii). The particular interest in the present thesis is in the text units that have a basic purpose of defining or elaborating terms, especially those using an identifying relational clause, as
mentioned above. Thus, to use the example from the discussion of Lay’s method on page 62:

\[ \text{The term to be defined} = \text{identifying relational clause} \]

the \textit{token}, which specifies the form (or sign, name, holder or occupant) of that being identified

e.g., \textit{science} \quad \textit{the investigation and analysis of natural phenomena}

e.g., \textit{biology} \quad \textit{the study or science of living organisms and vital processes}

Defining or elaborating terms can be accomplished through a number of grammatical constructions that can be interpreted in terms of the token/value relationship. These need not concern us here. However, a significant exception to the token/value construct is when a term is defined in terms of a list of attributes:

... where something becomes identifiable by having a particular set of attributes. Each of the attributes is a necessary condition ... but only the whole set is sufficient to define the term. This kind of definition tends to be used when the major classes in taxonomies are being established. Geographers [for example] look first for partial likenesses to establish principle groupings; sub classification then proceeds on the basis of partial difference. (Halliday & Martin 1993, p. 152)

Our example would look something like the following:

\[ \text{science [is or has or entails]} \]

\begin{itemize}
  \item investigation
  \item analysis
  \item concern with natural phenomena
  \item etc, etc
\end{itemize}

Before evaluating this schema, the nature of the relational clause needs to be clarified.

Relational clauses can be of three types (Halliday & Martin 1993, pp. 42-3):

1. intensive (the term science denotes ...)
2. possessive (science includes all the ...)
3. circumstantial (science is about the ... or science concerns the ...).
The notion of *circumstantiation* is set out by Halliday (1994, pp. 149-61) in some detail. In particular is the set of possible circumstantial elements he proposed (p. 151):

<table>
<thead>
<tr>
<th>Type of circumstantial element</th>
<th>Specific categories (subtypes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>extent</td>
<td>distance, duration</td>
</tr>
<tr>
<td>location</td>
<td>place, time</td>
</tr>
<tr>
<td>manner</td>
<td>means, quality, comparison</td>
</tr>
<tr>
<td>cause</td>
<td>reason, purpose, behalf</td>
</tr>
<tr>
<td>contingency</td>
<td>condition, concession, default</td>
</tr>
<tr>
<td>accompaniment</td>
<td>comitation, addition</td>
</tr>
<tr>
<td>role</td>
<td>guise, product</td>
</tr>
<tr>
<td>matter</td>
<td></td>
</tr>
<tr>
<td>angle</td>
<td></td>
</tr>
</tbody>
</table>

It appears that at least some of the circumstantial elements may be relevant categories for the present analysis; they could conceivably apply to definitions or summary statements of science. Some judgement is needed.

*Criteria for plausible categories*

Categories must meet certain criteria in order to be plausible. In seeking to show that there are plausible categories of the ways by which science is characterised in the literature, the present analysis sought to embody generally accepted principles of category construction, in particular to meet criteria, such as described by Holsti (1969, pp. 94ff):

1) The categories must *reflect the purposes of the research*. This is done by making explicit both the variables and the indicators used for categorisation. It results in a valid representation of concepts being discussed, and reliably guides the categorisation. For example, this study is not concerned with any relationship between the categorisation of meaning and the authors’ genders and nationalities.

2) The categories must be *exhaustive*, meaning all entries must fit into a category. This is demonstrated in the analysis of Tables A.2 to A.10, below. In fact, the sequential construction of these tables is made to accommodate all entries explicitly.

3) The categories must be *mutually exclusive*, meaning that no entry should fit into more than one category. In general, this was demonstrated easily in
the present analysis. Some classes, however, required greater consideration before placement. This seems to arise where the term includes a number of associations of meaning - no doubt the reason for its use - that require judgement as to the essential or core meaning. See the discussion of enterprise, below, as an example where a judgement was made to identify the core meaning as the basis for the classification.

4) The categories must be independent, meaning that the placement of one entry to a category should not affect the categorisation of any other entries. This is often difficult to satisfy, such as where the categories are rank orders or values along a scale: ranking an item third, for example, displaces all items already ranked lower than three. The categories proposed in the present study are not of this type and so satisfy the criterion of independence.

5) Each category should be derived from a single principle of classification, meaning they use similar levels of conceptual analysis. This is easily met in the present study, which is a semantic analysis: all categories are categories of meaning. There is no mixing with numbers of respondents, for example, which employs a different principle of classification.

**Difficulties with these pre-determined sets of categories**

Lay’s categorisation of causes and Halliday’s categorisation of circumstantial elements are unsatisfactory for the present thesis, on the basis of the first of Holsti’s criteria, above. First, their contribution to the search for patterns in the classes is unclear, addressing as they do the differentiae and not the classes themselves. It would be better to defer the question of categories of differentiae until any categories of classes could be determined. Secondly, neither Lay’s categorisation of causes nor Halliday’s categorisation of circumstantial elements appears to relate particularly well to the set of data we have as the list of classes, and as categories do not clearly relate to the purposes of the study. Thirdly, Halliday’s categorisation of circumstantial elements (types and subtypes) introduces a set of terms that is large and introduces complexities of grammar.
likely to be unsuited to the purpose of this thesis. Fourthly, while some of the circumstantial elements appear relevant, this analysis uses a restricted range of circumstances. More than this, the very nature of the text units means that this study is concerned with a limited range of grammatical resources, not just in terms of circumstance.

Fifthly, it is possible to reword many of the summary statements so that the intended meaning is preserved quite clearly, but in doing so changing the category of functional grammar. More particularly is the interest in this study in sentences which involve the clarification of a noun. The basic structure by which we refer to nouns, and modify nouns, is by a noun group, such as the study of humanity, that contains the nouns study and humanity. This is not a circumstance. Furthermore, it is possible to blur the distinction between the two: some phrases beginning with in or at could be either a circumstance or a noun group, depending on the context. While this illustrates the analytical power of a functional grammar approach for interpreting text, it introduces complexities that are unnecessary for the purposes of the present analysis. Sixthly, we have noted earlier that there exists a tradition of categorisation in terms of knowledge and/or processes, that Millar and Driver (1987) recognised in suggesting that purposes replace processes. We have noted already that it would seem useful to start by considering the categories already in use. Seventhly, one of the features of the grounded approach is that it provides opportunity for categories to 'emerge' from the data, a potential that may be wasted by imposing pre-existing categories.

Given the foregoing argument, examination of the differentiae was deferred until after the examination of the classes. The terms used as classes in Table A.1 are listed alphabetically in Table A.2. The application of and results of this semantic analysis are described in chapter 4.

6. Links to further analysis and theorising

We turn finally, from the semantic analysis and construction of categories of meaning, to the second and third parts of the present study: the extended discussion and
meta-analysis of the proposed categories as multiple dimensions of characterisation, (in Appendix B and chapters 6 to 11), and their application to the curriculum (in parts 4 of chapters 6 to 11 and in chapter 12).

The six companion chapters (chapters 6 to 11) summarise the selection, comparison and analysis of various metascientific arguments from the literature. Actual metascientific characterisations are given in sufficient detail in Appendix B to illustrate various arguments, for two reasons. The first is to show that a wide selection of metascientific argument and points of view can be adequately represented in the six proposed dimensions, which the present thesis interprets to mean that this literature characterises science in these six dimensions. The second is to indicate to science curriculum stakeholders the breadth and nature of characterisation of science in this literature.

On a number of occasions during the writing of this thesis it was tempting to structure this meta-analysis as a review of representative viewpoints followed by advocacy of a preferred view or characterisation. In other words, to provide more guidance to curriculum stakeholders. This approach was rejected as making assumptions about the desired nature of school Science on behalf of stakeholders. The approach adopted was to indicate something of the scope to be found, with an emphasis more on mainstream metascientific views, as judged more suitable to mainstream curriculum development. In this sense, the author's views have influenced the argument, in the selection of sources and authors and in the manner they are presented, but it is hoped that beyond the stated concern for mainstream views this influence has not been too obtrusive.

While no direct precedence for the present thesis has been found, there is some experience in the educational research literature to be drawn on, that serves as a guide to a meta-analysis such as attempted here. For example, Dunkin (1996) has described nine types of errors occurring in three stages of the process of synthesising research. We will use this review of errors as a benchmark for discussing the analysis of the metascientific literature.
In the first stage, or what Dunkin called the primary stage,

the synthesiser searches the literature and selects from it the items judged relevant to the topic of the review. Errors made at this stage result in bias that might lead to conclusions that represent the findings of only part of the research and omit the findings of the rest, or that give equal status to the findings of good and poor research. (Dunkin 1996, p. 88)

Thus the first type of error is unexplained selectivity, where the reviewer does not explain or justify why research is excluded that falls within the stated scope of the review. The result of this error is that the conclusions of the research cannot be claimed to apply to the whole field of concern. The present thesis, while claiming that a strictly accurate representation of the field (science and metascience) is an unreasonable expectation, has addressed this type of error in its procedure for identifying arguments. That is, it began its exploration of metascientific fields using authoritative, current and representative texts, such as The Philosophy of Science (Boyd, Gasper & Trout (eds) 1991), The History of Science (Bynum, Browne & Porter (eds) 1983), Companion to the History of Modern Science (Olby, Cantor, Christie & Hodge (eds) 1990), and Handbook of Science and Technology Studies (Jasanoff, Markle, Petersen & Pinch (eds) 1995). Aside from argument and explanation, these texts included extensive bibliographies and references that the present thesis used as further sources.

The second type of error is lack of discrimination, in which the reviewer fails to discriminate between the uneven quality of research on a topic. Dunkin’s main concern here was the lesser quality of non-refereed conference papers and reports, when compared to journal articles and texts that have undergone peer review. The present thesis has relied overwhelmingly on the latter, reviewed, category, and so avoids this criticism.

In the second stage, what Dunkin called the secondary stage,

the reviewer analyses the literature selected in order to identify context, methods, and the findings of each study included. This is the stage at which the variety of errors made is greatest ... (E)rror in identifying facts about contexts and methods leads to the misclassification of studies, and errors in identifying and reporting findings introduce error into the next stage of the synthesis. (Dunkin 1996, p. 88)

Thus the third type of error is erroneous detailing, where the reviewer makes wrong statements about the details of research. The present thesis has attempted to avoid this
problem by careful adherence to its source materials and extensive use of quotations to accurately represent the varied and often complex arguments in metascience. The fourth type of error is double counting of multiple reports from the one project, which does not apply to the present study and its concern with the variation and substance of argument, not its representativeness.

Potentially more damaging are the fifth and seventh types of error, respectively nonrecognition of faulty author conclusions, and suppression of contrary findings. In the former, the original authors do not represent their findings fully and reviewers accept these uncritically; in the latter, findings contrary to the reviewer’s generalisations are ignored. It is the nature of metascience that original authors put particular lines of argument and typically it is other authors who argue the faults in those arguments. The present thesis has attempted throughout to show that metascience is a complex field almost defined by opposing arguments and that for many, even most, characteristic issues, such as the role and defence of induction, there is no agreed solution. Thus in the majority of cases, the complexity and diversity of the field is best represented by presenting several views. For the sixth type of error, unwarranted attributions, the reviewer makes false claims about the results of studies; again, the close adherence to the original texts and extensive use of quotations should convince the reader of the veracity of the present thesis here.

In the tertiary stage, which applies particularly to the present thesis,

the reviewer seeks to assemble the evidence of the individual studies according to the main topics or issues investigated, in order to see whether meaningful and justifiable generalisations (syntheses) can be stated about them. The questions asked are, Do they add up?, and, IF so, to what? Errors at this stage can lead to the statement of invalid generalisations and to the failure to recognise valid ones. Of course, errors made at the primary and secondary stages seriously threaten the validity of generalisations at the tertiary stage, but it is also possible that errors can emerge at this stage for the first time. (Dunkin 1996, p. 94)

Dunkin identified two types at this stage. Thus the eighth type of error is a consequential error arising from errors at earlier stages. Since the earlier errors were rebutted, above, this type should not apply. The ninth type is failure to marshal all evidence relevant to a generalisation, where the present thesis interprets generalisations as the six dimensions of characterisation. The extensive size of the present thesis has resulted from addressing just
this question - marshalling sufficient evidence for the dimensions. This thesis argues that marshalling all evidence is an improbable feat, given the nature of the field and the task, and in any event unnecessary. Instead it claims to have marshalled sufficient evidence relevant to the generalisations, and leaves it to the reader to make this judgement.

In conclusion, the six companion chapters, together with the extended analysis in Appendix B, marshal a considerable amount of metascientific argument to make, support and illustrate the case for science being characterised in the proposed multiple dimensions. In doing so, it is recognised that much more argument could have been included but that, in the judgement of the author and the readers of various drafts, what has been finally included is sufficient to make the case. Indeed, there were several instances in the writing of the thesis of discarding sections in an effort to contain the overall length, because they added no further to the overall argument even though they were consistent with it.
Chapter 4

Application and results of the semantic analysis:
constructing dimensions of characterisation

The semantic analysis of a collection of summary statements about science given in the metascientific literature as a basis for identifying dimensions of characterisation

Introduction to the chapter

This chapter reports the application and results of the semantic analysis described in chapter 3. It interprets the resulting categories of meaning as dimensions of characterisation, to be applied in the extended discourse. It is structured as follows:

1. categorising the classes:
   a) classes meaning knowledge
   b) classes meaning activity
   c) classes meaning purpose
   d) classes meaning context
   e) classes meaning structure
   f) classes meaning some unstated mind-set;

2. classes with complex meanings;

3. characterisation as versus characterisation by;

4. the possibility of more, or fewer, categories of characterisation;

5. categories of meaning as dimensions of characterisation;

6. the relegation of terms to the differentiae;

7. the ‘content’ of dimensions;

8. the interdependent nature of the dimensions; and

9. conclusions and application of the results for further analysis and theorising.
Semantic analysis of the classes

The categorisation of the classes is a combination of the second and third types of categorisation, as described above. That is, it proposes the two traditional categories of knowledge and processes (or activities) as tentative constructs, to see what remains after they are extracted.
1. Categorising the classes

a) Classes meaning knowledge

The list in Table A.2 of classes identified in the summary statements clearly includes a large number of words used to characterise science in terms of knowledge or concepts. These are collected in Table A.3. This category is consistent with the traditional characterisation of science by its knowledge. However, the majority of classes remain uncategorised, which indicates that in many metascientific accounts knowledge alone is not sufficient to characterise science.

b) Classes meaning activity

From among the classes now remaining in Table A.2, a second set was extracted that were used to characterise science by activity of some sort, meaning that it is characterised by some sort of process, method, dynamic, development or change. This is consistent with the second traditional dimension of science, often called process. However, there appear to be several difficulties with labelling this set of terms as processes. First, the set appears to have a broader meaning than what are commonly regarded as ‘scientific processes’ such as predicting and experimenting. For example, the terms activity, behaviour and procedures are more general than this. Contention and developing statements appear to refer to different activities to what are commonly thought of as scientific processes. Secondly, there is also a collective imprecision in the ways these terms are used in the summary statements. Thirdly, terms such as enterprise (see discussion below) appear to have been employed explicitly because they embody a collection of meanings, in this case to associate purpose, large scale and context with activity. Fourthly, the term processes is subject to some debate within the science education literature, and it would be prudent to avoid any confusion with that debate. Accordingly, the present thesis labels this set of terms as activity, a term more likely to

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1 This is taken up in more detail in the dedicated companion chapter, chapter 10, and in Appendix B.5.
avoid any existing debates over related terms, yet which labels all the terms in the set. The set is collected in Table A.4.

c) **Classes meaning purpose**

Finding that science is often characterised by its knowledge and activities is not unexpected, of course. What may have been less expected, given the dominance of these two dimensions in the literature, is that a large number of terms for classes still remain after knowledge and activity have been accounted for. That is, for the majority of summary statements, knowledge and activity are not sufficient to characterise science. Consistent with the characterisation suggested by Millar and Driver (1987) of *purpose* instead of *processes*, it is worthwhile noting that, from the classes remaining in Table A.2, a third set was extracted in which science is characterised by its *purpose, intentions, goals* or *aims*. These terms are set out in Table A.5.

d) **Classes meaning context**

From the classes now remaining in Table A.2, a fourth set was extracted in which science is characterised by its *context*, such as *community, contextual, culture, entrenched, occupation/vocation, politics, society* and *tradition*. These are collected in Table A.6. Note that the term *tradition* can be taken as meaning an *intellectual tradition*, meaning it is referenced to ideas, or a *tradition within a social or sub-cultural group*, meaning it is referenced to cultural or social norms. These interpretations correspond to positions found in the literature, being characteristic especially of internalist and externalist positions respectively. This is a significant distinction in the characterisation of science, and is discussed in some detail in chapter 6. A number of the summary statements do not mention context, and a view of science is implied through this omission that science is acontextual; this corresponds to an extreme internalist position, in which only the intellectual context is considered.\(^2\)

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\(^2\) Again, this is taken up more fully, in the companion chapter on context and in Appendix B.1.
e) Classes meaning structure

From the classes now remaining in Table A.2, a fifth set was extracted that indicates a *structural*, *relational* or *syntactical* characteristic of science, such as *body*, *disciplines*, *institutions*, *laws*, *set*, *structure*, *systems*, and *theories*. These terms are set out in Table A.7. Terms such as *laws* and *theories* are commonly associated with their knowledge content, but this misses a significant element of characterisation. Scientific knowledge is not set out in any old fashion. It has characteristic forms or structures as well as purposes. Much of science is set out mathematically, in which the order or structure is highly significant; and scientific language derives its meaning and precision from its characteristic structures. According to some conceptions, a scientific theory is very highly structured and according to some others it is not, but in any case *structure* or *form* is a metascientific issue. Note that some terms may be considered to arise from an internalist approach, being concerned only with the intellectual context: *laws*, *theories* and *propositions* are commonly given as examples. Others correspond to an externalist position: *industries*, *enterprise* and *institution* are obvious examples. This apparent dichotomy might indicate that structural or relational aspects should be considered as two categories. However, a number of relational terms are ambiguous on this question, and could refer to either, especially when read in context: *tradition*, *discipline*, *system*, *fields of science* are examples. This indicates a mutual influence that the intellectual and organisational structures have on each other, and that their distinctiveness can be blurred. The term *structure* incorporates all these variations. This also is discussed later in the thesis.

f) Classes meaning some, often implicit, mind-set

From the classes now remaining from Table A.2, a sixth set was extracted which indicates a *foundational* or *dispositional* aspect of science, which is usually *unstated* or *implicit*, such as *attitudes*, *belief*, *belief system*, *commitment*, *criteria of judgement*, *fundamental conceptions* and *value posture*. These terms are set out in Table A.8. They indicate that science is at least partly characterised by some set of assumptions, attitudes, beliefs and values. Again, discussion of this proposed dimension is given more fully in a
dedicated chapter, chapter 7, where the case is made that these terms all comprise elements of a belief system.

2. Classes with complex meanings

Some terms had a number of associated meanings, from which a core or central meaning was interpreted, as mentioned above. This required some consideration of the meaning in the context of the surrounding text and the broader set of meanings as given by a dictionary. For example, the term *enterprise* means:

1. a project undertaken or to be undertaken, especially one that is of some importance, or that requires boldness or energy
2. engagement in such projects
3. boldness or readiness in undertaking, adventurous spirit, or energy
4. a company organised for commercial purposes (*The Macquarie Dictionary*).

In turn, the term *project* means:

1. something that is contemplated, devised, or planned; a plan; a scheme; an undertaking (*The Macquarie Dictionary*).

From this the term *enterprise*, as used in several of the summary statements, is interpreted as meaning a planned activity of some importance that requires some spirit of boldness. The possibility of such an extended explication reflects, no doubt, the authors' purpose in using the term *enterprise*. It is reasonable to suggest here, however, that the core meaning is *activity* or a synonym of it. It is also reasonable to suggest that the remainder of the explication can be analysed using the categories of characterisation proposed here: the characterisation of science as *enterprise* is reasonably interpreted as an activity that is planned (it has purpose), of significance (it has context) and is undertaken with particular attitudes (particular elements of a belief system).

3. Characterisation as versus characterisation by

Somewhat similarly, a small number of classes from Table A.1 remains after the six categories proposed above are noted. The remaining terms differ from those already accounted for in terms of their meaning: unlike those included in the six categories, the
remainder refer to science as a whole. They characterise science in its entirety as something. *Characterised by* does not have the same meaning as *characterised as*. For example, while a kangaroo may be *characterised as* a marsupial, it is *characterised by* more than just a pouch (or fur, or warm bloodedness, etc.) In this sense, we could be confident in claiming that science can be partly characterised by a body of knowledge, but very clearly from the analysis above, it is more contentious to attempt to characterise science as a body of knowledge. In considering these preliminary findings it is reasonable to suggest that the disagreements that arise in discussing whether science is a body of knowledge or a set of processes often arise because of this confusion of usage.

In this way we can interpret characterisations of science as a *world view/picture* (summary statements 16, 73, 74), a *vision* (61) and as *Natural and Physical Science* (80), as representing a different use of language, because at face value they represent complete characterisations of science. However, they can be ‘unpacked’ to make explicit the meanings tied up in the terms, which, in all cases encountered in the present study, can be understood in terms of the six proposed dimensions. Read in context, *science as a world view* and *science as a vision* can be understood as a set of beliefs, assumptions and criteria, as discussed in the companion chapter on *belief system* and Appendix B.2. *Science as natural and physical science* refers to a particular *context* of the notion of *science*, as discussed in the chapter on context. Several of the classes already categorised could be ‘unpacked’ in this way also: *enterprise* (statements 19, 27, 36, 85, 87) has been mentioned, but *research* (statements 41, 48, 50, 58, 69, 71) implies particular, goal-directed activities (purpose and activity), and *knowledge or intellectual activity* (statement 80) explicitly refers to knowledge and activity.

A second reason for not considering this use of the language is that the study would then be left open to accept every characterisation of science in terms of a metaphor: science as a *discourse*, science as a *tree*, and so on. While these may have their own insights, they represent a different set of data which would have to be dealt with separately and would include more idiosyncratic approaches and attendant difficulties in interpretation. There are two responses to this. One is to accept the minimal interpretation
of accepting *characterisation by*, and leave aside *characterisation as* because it is an unnecessary complication in the present study. Borhek and Curtis (1975), for example, discuss science as a belief system as part of their book on beliefs; they may or may not have views about science as a process, etc. All we can say is that at the least they characterise science partly in terms of beliefs. That is sufficient for inclusion in one of the six proposed categories of characterisation.

The other response is to 'unpack' the term, as discussed above. So, for example, the claim that *science is language* can be approached by examining the term *language*, as given in this summary statement:

> Language (like other social semiotic systems) is a dynamic open system that achieves metastability through these statistical processes. (Halliday & Martin 1993, p. 110)

Thus in turn, language can be understood in terms of the dimensions already proposed: context (*like other social semiotic systems*), activity (*dynamic, metastability, processes*), structure (*systems, open system, statistical*), and rules as elements of a belief system (*statistical*). Within this summary statement, the term *semiotic* can be 'unpacked' in turn. Understood as pertaining to the 'theory and study of signs and symbols' (*The Macquarie Dictionary*), the term *semiotic* can be analysed in terms of these same proposed dimensions: activity (*study*), and structure (*theory, signs, symbols*). In turn, *signs* and *symbols* as part of a communication, can be explicated in terms of activity, purpose and context. The point is that language is not a seventh dimension, but rather another construct which can be understood in terms of the six dimensions already proposed. In other words, it is suggested here that the way to include such entries in the present exercise is to subject them to an additional stage of analysis that deconstructs their figurative meaning: to examine what characteristics of trees or rivers, for example, are analogous to science. The branch-like structure and dynamic growth of the tree, for example, are characterisations respectively in terms of structure and processes, which again are categories identified above.
4. The possibility of more, or fewer, categories

Of course, it will always remain a possibility that a term or terms will be found that will not fit any of the proposed categories of characterisation, requiring the addition of a seventh, eighth or greater number of categories. To this there are two responses. First, no terms of this type were found; the categories proposed were constructed as set out in this chapter in order to account progressively for all terms called Classes. Secondly, it was acknowledged in chapter 3 that such categories are created, not discovered, and it remains an option of the writer to propose as few or as many as the writer can justify.

Given the parameters discussed earlier, the data collected and the analysis adopted, the traditional characterisation only in terms of knowledge and processes is judged to be inadequate, for many reasons. Alternatively, an extensive collection of categories of finely distinguished meanings is judged to be unsuited to the purposes of the analysis because it introduces a complexity unsuited to the school curriculum. In acknowledging that these categories are constructed and not discovered, it is acknowledged that another analyst could construct a set of categories that is completely different, or partly different by sharing only some categories, or partly different by adding categories. The present analysis can claim no more than any other analysis in developing a system that suits its purpose, applying it systematically so as not to distort the data, and constructing a plausible and useful account. It will additionally claim, however, that it presents a more plausible and comprehensive attempt to characterise science for the purposes of curriculum development than has been available hitherto.

5. Interpreting the categories of meaning as dimensions of characterisation

It should be made clear that the semantic categories identified in this study are categories of meaning and not in themselves proposed as categories of science itself, however that might be construed. That is, they are categories of the ways in which
scholars characterise science; we can attach no more significance than that. However, a potential problem with the term *categories* is that it might encourage the reader to interpret them as discrete entities or even, in a nominalist approach, vesting them with independent existences. This would be misleading and a misrepresentation of the findings of this thesis. Therefore the thesis uses the term dimensions rather than categories, meaning that scholars interpret different dimensions or viewpoints on the same topic of analysis, that is, science. It is possible to have multiple dimensions of interpretation of the one subject, and that is precisely what is proposed here: that scholars characterise science in multiple dimensions, where the characterisation involves a set of mutually interactive, multiple dimensions.

6. The relegation of terms to the category *Differentiae*

At this point the reader may object that there was a degree of arbitrariness in classifying some units of text in Table A.1 as either belonging to classes or differentiae. Some examples could have been reworded in more than one way such that the meaning of the original text was maintained, yet the class in one version could almost as easily have been relegated to the differentiae in another. The criticism is not that the meanings in the raw data - the original text unit - are lost, because a careful comparison of Figure A.1 (the summary statements) and Table A.1 (the content analysis of the summary statements) should convince the reader that the meanings are retained. Rather, the criticism could be that some of the text units may have been arbitrarily assigned to being differentiae and so excluded from the semantic analysis to which we have just subjected the classes. If this were the case, it may be possible that some of the differentiae are not adequately categorised by the six categories proposed.

As a check against such a potential criticism, the text units identified in Table A.1 as differentiae are set out in Table A.9 according to the six categories of characterisation proposed in the analysis to this point. There are two conclusions to be made:

1. Table A.9 makes clear that, with the exception of the factor identified in (2) below, the text units assigned to the differentiae can be categorised in the same six
ways as the classes, meaning that we only need to be concerned with the six proposed categories, and not with the status of classes versus differentiae. Classes and differentiae thus represent analytical tools by means of which the proposed categories of characterisation were identified, and need not be the concern of the end-users of this theorising. Lay’s approach to the differentiae appears clearly unsuited to the present exercise, and can now be disregarded.

A smaller number of differentiae remain as not clearly belonging to any of the six semantic categories. These text units have the form of nature, or of the environment, or of humanity and the universe. Their form means that they could not have been the subject of a sentence, and so could not have been a class. They represent what is often called the content of the knowledge. They are included in Table A.9 in italics in the column of the category to which they directly refer in the original text, not in the category of the class of the original text. From this we see that they also serve to indicate the content of at least some differentiae, namely knowledge, activities and foundational. The question immediately arises, Do these text units constitute a seventh dimension? The answer is no, not in terms of the way the present set of dimensions is being proposed. First, none of the summary statements fundamentally characterised science in terms of, for example, science is of Nature; rather, it is always knowledge of Nature, or investigation of Nature, or beliefs about Nature. Second, it makes no sense to talk of knowledge, for example, without the content of that knowledge. Knowledge, activity, structure, purpose, context and belief system do not in themselves characterise science, for it may be that as they stand those dimensions could apply to other endeavours such as history. That possibility is explored tentatively at the close of the thesis. But if their content is wholly or partly of humanity and the universe, then we have a thorough concept of science. Table A.11 contains a detailed analysis of a small number of summary statements in terms of the proposed dimensions. The content of humanity and the universe, or some variant with similar meaning, is shown to apply either directly or indirectly to all dimensions.
7. The ‘content’ of the dimensions or categories

We therefore turn to the question of the ‘content’ of each dimension. Where it is given, the summary statements generally share a common focus, that is, the knowledge, activities and beliefs are of or about Nature, the universe and/or the environment:

- natural world (summary statement 3),
- man and his environment (summary statement 1),
- the world around us (summary statement 4),
- some aspect of reality (summary statement 8),
- our sense experience (summary statement 10),
- the many particulars of empirical evidence (summary statement 11),
- the physical and biological world (summary statement 13)
- the world and our place in it, the world, the nature of reality, reality (summary statement 14)
- reality, the wide world of sense impressions (summary statement 15)
- [a view of] the world (summary statement 16).

The qualifier generally was included above for two reasons. Firstly, not all the quotes state their focus, and those that do vary from broadly to narrowly focused, as can be seen in the extracts above. Table 4.1 below shows how a summary statement from Figure A.1 can be ‘unpacked’ into segments corresponding to dimensions. Thus, statement 3 ‘unpacks’ as follows:

[Science is] all exploratory activities of which the purpose is to come to a better understanding of the natural world.

This can be reworded to clarify activities as the class:

[Science is] ... activities [that are] exploratory [and] of which the purpose is to come to a better understanding of the natural world.
The reworded version can then be ‘unpacked’ and interpreted in terms of the proposed dimensions and their linkages:

Table 4.1
Analysis of a summary statement into dimensions

<table>
<thead>
<tr>
<th>Original/reworded text</th>
<th>Analysis by categories of characterisation (given in bold type)</th>
<th>Linkages of categories of characterisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Science is] activities</td>
<td>[Science is] ACTIVITY</td>
<td>ACTIVITY</td>
</tr>
<tr>
<td>[which are] exploratory</td>
<td>[which are] a subset of activities</td>
<td>ACTIVITY : activity</td>
</tr>
<tr>
<td>[Science is also] ACTIVITY</td>
<td></td>
<td>ACTIVITY</td>
</tr>
<tr>
<td>[and] of which the purpose is to come to a better understanding of the natural world.</td>
<td>which has as a purpose</td>
<td>ACTIVITY : purpose</td>
</tr>
<tr>
<td></td>
<td>the activity of coming to knowledge of the natural world.</td>
<td>purpose : activity</td>
</tr>
<tr>
<td></td>
<td>of the natural world.</td>
<td>activity : knowledge</td>
</tr>
<tr>
<td></td>
<td></td>
<td>knowledge : natural world</td>
</tr>
</tbody>
</table>

Thus statement 3 can be interpreted as follows:

i. Science is an activity.
ii. This particular type of activity is exploring.
iii. This activity is purposeful.
iv. The purpose is to ‘come to’ (an imprecise word indicating change or development, which is another sense of activity).
v. What is ‘come to’ is knowledge.
vi. The knowledge is of the natural world.

Thus *of the natural world* is the content, strictly speaking, of the knowledge. It is extra information about the knowledge. In turn, the knowledge is the ‘content’ or extra information of the activity ‘coming to’, which in turn is the content of the purpose, which in turn is the content of activity. This represents a series of links:

Each of the dimensions activity (twice), purpose and knowledge relates either directly or indirectly to the content of the natural world, and the dimensions activity (twice) and purpose relate directly to other dimensions. The notion of the content of dimensions sometimes being other dimensions is consistent with the commonsense notion of science partly involving knowledge of activities, of structures, etc. That is, science not only involves doing activities, for example, but knowing about them and understanding them. Thus the content of the dimensions is humanity and the natural world, or something equivalent, and the other dimensions.

8. The interdependent nature of the categories or dimensions

Finally, and related to the matter of interconnectedness raised in the preceding paragraph, the complexity of many of the summary statements in Figure A.1 is not fully identified in the analysis to this point. The concern addressed above, whether the assignation of a piece of text as the class or in the differentiae makes a difference, arises because two or more categories are linked in many of the examples. Table A.10 sets out the entries in Figure A.1 (where the numbers indicates the entry number in Figure A.1) in terms of the categories of categorisation of the classes against those of the differentiae. It shows that, for some cases, the meaning of the class (say, knowledge) is explicated in terms of the same category of meaning in the differentiae (i.e. knowledge), but for others the class (say, knowledge again) is explicated in terms of other categories (such as processes). In the example above, the class activity was explicated by differentiae of activity, purpose and knowledge. Table A.10 indicates that, although individual authors in the metascientific literature typically claim to characterise science in one or two dimensions, up to six dimensions are employed typically in their overall characterisation. That this is not obvious is due to these extra semantic resources being embedded within the text.
Conclusions

It is reasonable to conclude from the analysis of data in Tables A.1 to A.10 that

(1) a characterisation of science in terms of only its knowledge content, or processes, or both, is not comprehensive;

(2) it is not sufficient to conclude simply that science can be adequately characterised in just one dimension;

(3) a comprehensive categorisation of science is more adequately made by accounting for a set or cluster of six dimensions derived from a semantic analysis of summary statements: knowledge or conceptual framework(s), process(es), purpose(s), belief system(s), structure(s) and context(s);

(4) the six dimensions are interdependent and should be considered in combination; and

(5) the content of these dimensions is humanity and the universe, and the dimensions themselves.

The conclusions of the foregoing semantic analysis of summary statements of science from the metascientific literature are that in the examples studied:

(1) science is characterised in the metascientific literature in terms of one or more of six dimensions: knowledge, process, purpose, structure, context and belief system;

(2) these dimensions of characterisation are typically used in combination;

(3) the content of these dimensions is humanity and the universe, and the dimensions themselves; and

(4) a comprehensive characterisation of science may be constructed utilising all six of these dimensions.

Further points, which are more tentative at this stage of analysis, will be explored more fully in the six companion chapters and Appendix B, that set out a case for each of these six dimensions:
(5) different views or characterisations of science in the metascientific literature, curriculum documents and elsewhere can be analysed and compared in terms of this six-dimensional framework;

(6) the six dimensions or categories of characterisation are ‘interactive’ in the sense that they influence each other. A position taken in one dimension will affect the options available in the remaining five. It also indicates that, if science is considered to be multifaceted in some way, the integrity of the whole may be lost by considering the facets out of context and disconnected from other meanings. This lends support to Bronowski’s claim (see summary statement 16) that science is a ‘highly integrated form of knowledge which makes a world view’; and

(7) this six-dimensional framework for the characterisation of science is more suitable than existing frameworks for the characterisation of science for inclusion in the school curriculum.

Conclusion of this analysis

The question remains, what is it that meaningfully or appropriately characterises science for inclusion in the curriculum? In part, the answer is that it depends on what criteria we are using to frame the curriculum. The philosopher of education Paul Hirst (1974), for example, was concerned mainly with the knowledge. It will be argued in chapters 6 to 12 and in Appendix B that the six dimensions are each necessary but not sufficient to characterise science, and that science results from the interactions of these dimensions. The application of the proposed theoretical framework will be addressed following the six chapters explicating the proposed dimensions of characterisation of science.
Chapter 5

INTRODUCTION TO THE SIX COMPANION CHAPTERS

Science is characterised in the metascientific literature by a set of six interdependent dimensions, being knowledge, activity, structure, purpose, context and belief system in combination, the content of which is Nature, including humanity, and the dimensions themselves.

Having constructed six categories of meaning from a semantic analysis of summary statements of science from the metascientific literature, there now follow six companion chapters, one dedicated to each dimension, which examine some of the ways in which these meanings are made in that literature. The argument to be made is that each dimension is a necessary, but not sufficient, characteristic of science. Each is necessary in that the meanings of characterisation in the metascientific literature are incomplete without it, and it does not reduce to any of the other dimensions. None is a sufficient characteristic of science in that none alone completely characterises science. Each of these six companion chapters follows a common format of four parts:

1) evidence from the analysis of the summary statements in Figure A1, from which the six proposed dimensions were constructed;
2) a summary only of evidence from argument in the metascientific literature, to direct the reader to some issues of recurrent interest concerning the dimension, and explore some of the subtleties entailed, given in Appendix B;
3) the relationships between the dimension and the other dimensions;
4) conclusions for theorising about the science curriculum.

1. Evidence from the summary statements

Each companion chapter begins with this section, to draw attention to relevant meanings from the summary statements. The six dimensions constructed in the analysis of
the summary statements are semantic categories, i.e. categories of meaning, that are the basis for suggesting six dimensions of characterisation. This is a means of ensuring the argument for characterisation is grounded in the semantic analysis of the metascientific literature. Each of these sections also includes a list of appropriate text units from just the first twenty summary statements. To provide the complete list from the summary statements would merely reproduce the data given in the tables in the appendix. These examples are given simply to illustrate, first, that even within the first twenty summary statements the general notion of the dimension applies in various ways, and secondly, that there is a sound base of data on which to construct a more thoroughgoing argument for a category or dimension of characterisation.

2. Evidence from argument in the metascientific literature

This section is included to show something of the breadth of scope of characterisations in the literature. As already stated, this thesis does not seek to provide simply a metascientific discussion, but to inform the use of metascientific discussion in the development of the science curriculum. Each of the six suggested dimensions is a broad category of meaning, probably much broader than most readers would have expected initially. The summary statements are by definition extracts from the metascientific literature selected because they summarise or encapsulate an author’s view of science. Their purpose was to provide data for collecting and categorising such succinct expressions of view. However, they do not express the extended arguments usually given in making and justifying these views; this is the purpose of section 2 and the related metascientific discussion in Appendix B.

We have mentioned both the immense quantity and scope of the metascientific literature, and the intention of this thesis to provide a common framework of this literature for all science curriculum stakeholders. Some stakeholders are very familiar with this literature, others have scant familiarity with it, and yet others have deep knowledge of, and commitment to, only particular views or fields. With this in mind, this section seeks to select and present sufficient arguments, and in sufficient detail, to show how the literature
uses various issues to characterise science in a particular dimension of meaning. The detail is intended to be sufficient in both the number and range of examples, and discussions of the examples themselves. The reader familiar with that area should be satisfied that some characteristics have been included and their contribution demonstrated, while not belabouring the point with detail available elsewhere. The reader less familiar with a field should be satisfied that the discussion provides sufficient detail to indicate how a range of arguments contributes to characterisations of science.

As to the metascientific literature itself, an attempt is made to include a range of analyses of metascientific views. In some places, historical examples are given to illustrate the contribution of particular views, but the general concern is with the views that are considered to be current in the latter half of the twentieth century, and their immediate antecedents.

2.1 Comparison of metascientific views

Each of the six companion chapters presents an overview of metascientific analyses, to enable a comparison not just of views, such as inductivism or realism, but of analyses or categorisations of views. These overviews are given in Appendix B: Table B.1.1 for Context, Table B.2.1 for Belief System, Table B.3.1 for Purpose, Table B.4.1 for Structure, Table B.5.1 for Activity, and Table B.6.1 for Knowledge. Each of these tables compares the same authors and follows the same format, in order to show how each dimension applies to our understanding of various metascientific views.

The six tables draw on standard references and authoritative summaries of the current state of central metascientific fields:

- *The Philosophy of Science* (eds Boyd, Gasper & Trout 1991, typology given by Boyd, Gasper and Trout) for philosophy of science;
Chapter 5: Introduction to the companion chapters

- *Handbook of Science and Technology Studies* (Jasanoff, Markle, Petersen & Pinch (eds) 1995, typology given by Callon) for science and technology studies (henceforth STS); and

- *The Structure of Scientific Theories* (ed. Suppe 1979) as a statement of history and philosophy of science (henceforth HPS) made at the time of the decline of the positivist Received View.

*Classroom conceptual change: philosophical perspectives* (Nussbaum 1989) and *From science as knowledge to science as practice* (Pickering 1992) are included from texts with HPS and STS approaches, respectively.

In the post-positivist era of HPS, three positions dominate and indeed are interpreted as comprising a new but complex consensus (Boyd Gasper & Trout 1991). The central tenets of the HPS traditions that apply more clearly to this current consensus are that science turns on sense experience (in *empiricism*), on the personal or social construction of beliefs and knowledge (in *constructivism*), or on the existence of an independent reality or assumptions about Nature (in *scientific realism*).1 Note that there is a variety also of views from within notionally STS perspectives (as given by Callon 1995), and furthermore that there are significant overlaps between various views.

Thus each of the six companion chapters includes (in Appendix B) a table for its dedicated dimension (Tables B.1.1, B.2.1, B.3.1, B.4.1, B.5.1 and B.6.1). These set out

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1 The glossary in Boyd, Gasper and Trout (1991) defines these terms as:

*Empiricism:* The view that all knowledge is based on or exhausted by what is known by sensory experience.

*Scientific realism:* The view that the subject matter of scientific research and scientific theories exists independently of our knowledge of it, and that the goal of science is the description and explanation of both the observable and unobservable aspects of an independently existing world.

*Constructivism:* The view that the subject matter of scientific research is wholly or partly constructed by the background theoretical assumptions of the scientific community and thus is not, as realists claim, largely independent of our thoughts and theoretical commitments. (Cf. Neo-Kantianism.)

*Neo-Kantianism:* Another name for constructivism, the view that the reality described by our scientific theories is a social and intellectual construct and thus is not, as realists claim, largely independent of our thoughts and theoretical commitments. The name suggests an association with the views of the eighteenth-century philosopher Immanual Kant, but this association is exegetically controversial.
six metascientific analyses as an indication of the variety of metascientific approaches in the literature. The tables each have the following structure:

Table [Dimension] 1

Examples of characterisation of key metascientific viewpoints by [Dimension, eg, activity, knowledge, etc.]

<table>
<thead>
<tr>
<th>Author</th>
<th>Viewpoint</th>
<th>Examples of reference to [dimension]</th>
<th>Identified in the work of ...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Author(s) and date of publication providing categorisation of viewpoints. Other authors may also refer to these categories of viewpoints. Many authors can be represented by more than one label.</td>
<td>Categorisation of viewpoints according to author(s), eg, empiricism, science as rational knowledge, constructivism. The categories of views are not discrete.</td>
<td>Examples of how the particular metascientific view employs this particular dimension (activity, purpose, etc)</td>
<td>Various thinkers whose work has been associated with this viewpoint</td>
</tr>
</tbody>
</table>

Each table presents the six authors in the same order, which is chronological by publication date.

Thus Suppe (1979) focused on the philosophy of science in roughly the first half of the twentieth century. Writing in 1973, Suppe provided (1) a comprehensive account of the Received View of scientific theories, the positivist viewpoint that was the dominant metascientific view for much of the first half of the twentieth century, and the viewpoints in philosophy of science that appeared to be competing to replace it: (2) sceptical descriptive analyses, (3) Weltanschauungen (world-view) analyses, and (4) semantic approaches. In
the Afterword of the 1979 second edition, Suppe notes the decline of the extreme *Weltanschauungen* analyses as favoured views and the emergence of (5) scientific realism as a strong contender. Suppe’s view is that historical realism is concerned to represent the actual practices of science, ‘both historical and contemporary’:

Contemporary philosophy of science rapidly is becoming philosophy of science - a discipline concerned with science as actually practiced yet at the same time doing philosophy ... Contemporary philosophy of science increasingly is coming to realise that there are ‘patterns of reasoning in the construction or discovery (as well as the ultimate acceptance or rejection) of scientific hypotheses and theories and that a great deal of illumination of the scientific enterprise can be attained by examining them’ (Shapere 1974) and that the philosophical examination of them is central to a viable philosophy of science. (Suppe 1979, p. 650)

Bhaskar (1983k) identified three main views that have been historically significant. Two of these are based mainly on activities: *observation* as the basis for empiricism, and *mental construction*, involving *reasoning* in various ways, as the basis for idealism. The third alternative, realism, is based on beliefs about Nature, but the variants of realism are distinguished in part by the investigative activities of Nature: (1) *reasoning* to ascertain an abstract reality (in Platonic realism), (2) *observation* to ascertain a material reality (in Aristotelian realism), (3) *perception* of a material reality which is independent of perceptions (in perceptual realism), or (4) *perceptions and other activities (including social activities)* of scientists, concerning the objects of scientific inquiry (in scientific realism).

Nussbaum (1989) identified three main traditions or viewpoints in his discussion of alternative philosophical frameworks for studying the history of science. The historically significant viewpoints are characterised in terms of (1) *reasoning* (in rationalism) and (2) *observation* (in empiricism and positivism). For Nussbaum the current viewpoint is characterised by (3) *construction of the best available knowledge* (in constructivism).

Boyd, Gasper and Trout (1991) categorised views somewhat similarly to Bhaskar. However, they tended to emphasise more the late-twentieth century consensus in the philosophy of science. They proposed *observation* in scientific realism, *construction* in neo-Kantian constructivism and *observation* in post-positivist empiricism as the three main alternatives in the complex consensus following the demise of the traditional positivist empiricism that dominated the field for much of the twentieth century.
Pickering (1992, p. 7) took the ‘stock appreciations of scientific knowledge’ to be ‘objective (logical empiricism), as relative to culture (Kuhn, Feyerabend), [or] as relative to interests (SSK)’. These three correspond broadly to philosophy of science, sociology of science and sociology of scientific knowledge (henceforth SSK). The present thesis interprets the foci of these approaches as belief system (criteria for judging objectivity), context (culture) and purpose (interests).

Callon (1995) has proposed four models of scientific development as a framework for reviewing STS approaches. There does not appear to be the consensus (if loose) within STS that Boyd, Gasper and Trout claimed for HPS, but Callon’s (1995) four models of scientific development provide an authoritative review of the field. Callon’s models are in themselves characterisations chiefly in terms of activity. These are, (1) science as rational knowledge; (2) science as a competitive enterprise; (3) science as sociocultural practice; and (4) science as extended translation. In terms of the categories already sketched above, at least models 2, 3 and 4 assume the construction of knowledge as central, and may be considered as variants of constructivism.

A comment on using and classifying metascientific views

The present thesis takes a cautionary approach to discussing and clarifying metascientific views, including notional fields of metascience like HPS, STS, SSK and so forth. Although some argue that there is a post-positivist consensus in HPS (see Boyd, Gaspar & Trout 1991), there is no similar consensus in STS (Edge 1995) except perhaps that STS has supplanted HPS (Shapin 1992), although this is contested by others (for example, Matthews 1994). In any event, such comparisons draw too simplistic a distinction between STS and HPS for the purposes of the present thesis, because they diminish the very diversity and overlapping characterisations it seeks to map (Shapin 1992). The present thesis interprets each viewpoint (such as empiricism, constructivism, etc.) in multiple dimensions, or as a complex of characteristics. The method used to explicate these metascientific views is to focus initially on one dimension at a time, dedicating a chapter to each.
There is considerable debate in the literature over competing metascientific theories, the more significant being included in this section of the companion chapters and in more detail in Appendix B. Emphasis is given to contributions to this debate from the philosophy, history and sociology of science; references are made less commonly to analyses from other fields such as science policy, psychology and linguistics. For example in recent years there have been challenges made against the adequacy of the philosophy of science itself (a largely Anglo-American tradition) from theorising within a largely French-German tradition of the nineteenth and twentieth centuries (known sometimes as continental epistemology). Alcoff (1992, pp. 77-81) has described five main approaches from the tradition of continental epistemology: phenomenology, critical theory, hermeneutics, post-structuralism and feminism. The impact each of these traditions has made on thinking within the scientific community varies, but their cumulative effect has been more significant from within the sociology of science, which in recent years has succeeded in broadening the scope of theorising about science. There are attempts to account for science within each of these traditions, and accounts within particular traditions necessarily deny accounts from some of the other traditions. Even attempts to characterise science in terms of a rejection of metaphysics employ discussions of metaphysics. Thus positivism is a tradition within the philosophy of science that denies metaphysics, but the point remains that in that characterisation the concept of metaphysics is still employed, albeit negatively. (See, for example, Schlick 1979). The relative merits of different claims from the sociology of science, and their challenges to the philosophy of science, are therefore included in this section. Theories from within these traditions draw upon scholarship in psychology and history, and mention will be made of these where necessary.

It is to some extent arbitrary in choosing where to begin such an overview, since much of the discussion in the literature draws upon more than one of these fields in its theorising. In particular, it is clear that discussion of how our knowledge of the cosmos can be justified will draw upon how we claim to have such knowledge and will imply particular views about what there is we can claim to have knowledge of. Conversely, claims as to the nature of the cosmos will imply particular theories of how we can claim to have knowledge
of such a cosmos. That is, a useful understanding of the relative merits of various theories of metaphysics, both in its general sense and as epistemology and ontology, is possible only if there is some understanding of several theories of each, and particularly those under current debate. Claims from the sociology of science are no easier, for these are mostly theorised by beginning with the inadequacies of the philosophy of science, against which sociological accounts are proposed as better alternatives. (I do not take this to mean that sociological accounts cannot be established without recourse to the philosophy of science. It is clearly in the interest of making a convincing case for an alternative that account be taken of the shortcomings of that which one seeks to replace). Following this precedent, sociological accounts are often considered after other accounts.

It must be emphasised that metascientific positions such as described above are merely labels for different interpretations or characterisations of science. The present thesis therefore rejects dogmatic characterisations of science, and is cautious about the use of broadly encompassing labels such as HPS and STS. We have mentioned that each of the positions above assumes a role in science for certain activities such as observation and experimentation. Further, there are some broad, if partial, similarities. Most generally, empiricists, constructivists and realists ‘largely agree’ that science knowledge is useful or instrumental (Boyd 1983, p. 211); what they disagree on is why science knowledge seems to work, and under what conditions it succeeds or fails. Nor do the differences correspond to alternatives between HPS and STS traditions: there are similarities and differences both within and between these traditions. For example, within the HPS views mentioned, mental constructions are rejected in some views but central to others such as constructivism and scientific realism. Within the STS views mentioned, most but not all of Callon’s models assumes the construction of knowledge as central, and may be considered as variants of constructivism.

Many current characterisations of science are not as distinct as the labels and their historically antecedent exemplars would suggest. For example, all assume experimentation and laboratory work, and most are now concerned to describe actual rather than idealised scientific activity. Thus although various STS approaches emphasise different
characteristics, each of Callon’s four models provides different insights by focusing on other scientific activities. Likewise, Bhaskar’s scientific realism acknowledges activities of social or cultural context:

Three main positions characterise the history of philosophical reflection on the natural sciences. For empiricism, the natural order is given in experience: for idealism it is what we make or construct; for realism, it is given as a presupposition of our causal investigations of Nature, but our knowledge of it is socially produced, and it is the nature of objects which determine their cognitive possibilities for us. (Bhaskar 1983k, p. 363; emphases added).

Within the context of the history and philosophy of science (HPS), Bhaskar and Boyd, Gasper and Trout have identified the contemporary metascientific position as being covered by post-positivist empiricism, constructivism and scientific realism, within which individual authors accept variously insights from competing positions. The consensus position in post-positivist HPS admits socio-cultural or psychological activities (such as constructivism generally and scientific realism). This is broadly consistent with positions in STS, of which Callon identifies four. For curriculum theorising, then, doctrinaire approaches to particular metascientific fields seem unwise, and in any case for the present thesis they represent only some of the many views it seeks to map.

Much of the metascientific literature, especially philosophy of science, is or has been concerned with determining what science should be, rather than what it is. A general science education must address what science is. The present thesis argues that curriculum developers should begin answering that question by comprehensively reviewing the literature about science - the metascientific literature - rather than arguing from a particular position within the literature, such as a normative view of science.

2.2 The impact of the Received View of science in the metascientific literature

There are many references in this thesis to the positivist Received View which, to avoid repetition, should be explained here. In developing an overview of metascientific views in the twentieth century, one cannot but be struck by the impact of one particular view or cluster of views, sometimes referred to as the Received View (Suppe 1979) or less precisely as the ‘standard view’. The Received View (henceforth RV), which dominated metascientific interpretation from roughly the 1920s to 1960s, was a version of logical
positivism or logical empiricism. The differences between logical positivism and logical empiricism are not usually significant in the present thesis, and so the term RV is used in this general sense.

Part of the influence of the RV was that it is a normative account of science, i.e. it purported to set out what science should be - what methods should be used, what assumptions should be made, what criteria should be applied, and so on. A normative account is not subject to the pressure of corresponding with what is the case, as is applied to descriptive accounts. Quite the opposite is the case when the dominant view is normative: it creates a pressure on other accounts to match the interpretation it has prescribed.

The RV was rejected progressively in the philosophy of science in the 1960s (Brown 1977; Suppe 1979) and in the sociology of science. The metascientific literature since that time tends to characterise itself as post-positivist, a term which the present thesis adopts. A good deal of the metascientific literature that is critical of the philosophy of science, such as much in STS, refers to variants of the RV in making its criticisms, that most post-positivist philosophy also rejects. However, the RV, or at least elements of it, remains influential and a resource in some fields, including among philosophically inclined scientists and in popular (lay) characterisations of science:

Although ‘dead’ in philosophy, positivism lives in the sciences: as a tendency of thought, in the natural sciences; and as very much more than that, in many of the human sciences. (Bhaskar 1983i, p. 335)

The RV still influences many who have or are studying for science qualifications, such as science undergraduates and science teachers (Gallagher 1991; Lederman 1992). Many school and undergraduate science texts typically present a view of science knowledge that is strongly influenced by positivism. The decline of the dominance of the positivist RV is therefore variable: strong within much post-positivist metascientific literature (HPS and STS), but patchy in broader contexts.

The point of this discussion is to emphasise the influence on thinking about science from a particular normative account that provided a prescription of science that in many respects was quite narrow, i.e. a particular belief system, particular activities, structures, contexts and purposes resulting in particular knowledge. This is not to argue that normative
accounts are obsolete strategies in current conceptions of science: some current metascientific approaches are explicitly normative (see, for example, Fuller 1991) but in the complex of viewpoints that oppose the RV, the normative/descriptive distinction is regarded as no longer relevant. Indeed, in some views this distinction was never significant, because it arose out of the RV itself and does not arise from the viewpoints currently debated (Brown 1977). On balance it would be misleading to characterise metascience simply as having moved from positivism to post-positivism. A more defensible interpretation would be to argue that positivism no longer enjoys the dominance it once had, and that various post-positivist views have presented strong critiques of it and alternatives to it that are probably not widely appreciated beyond the metascientific academic community. The present lack of a single, dominant received view of science is an argument for the present thesis to clarify a complex field for curriculum developers.

2.3 Current metascientific views

Given this discussion, post-positivist metascience is characterised not so much by the (uneven) demise of positivism, but by the emergence of different views of science and vigorous debate between them. At the close of the twentieth century, none of the alternatives to the RV commands a similar consensus. Nor is such a consensus likely into the foreseeable future, because of vigorous debates between and within different fields of metascience. This was the case in HPS from about the 1970s (Suppe 1977), although a complex consensus of several viewpoints could be discerned by the 1990s (Boyd, Gasper & Trout 1991, pp. xii-xiii). Part of the trend in recent philosophy has been towards interpreting and accounting for the insights of different perspectives:

In the modern period ... philosophy turned from its previous preoccupation with metaphysical questions to a primary concern with the possibility and nature of knowledge. This 'epistemological turn' was to dominate philosophy for two centuries, only to be replaced in the early part of this century, at least for Anglo-American philosophy, by a 'linguistic turn'. By analysing language, it sought to achieve many of the same goals that epistemology seeks in analysing the mind. The linguistic turn has been characterised by preoccupations with the structure of language, word-world relationships, and the analysis of meaning. Recently, however, the views about the foundations of knowledge and the knowing subject that were the basis for the epistemological turn have been called into question, and it has seemed to many philosophers that language and meaning cannot bear the kind of weight the linguistic turn required.
These challenges have been joined by developments in the philosophy of sciences and the hermeneutic tradition, pointing toward a new direction in philosophy characterised by an interest in interpretive activities. This 'interpretive turn' has benefited from the interpretive practices of such disciplines as literary criticism, cultural anthropology, jurisprudence, historiography, and feminist theory. With philosophy's redirection of attention to the interpretive disciplines, however, the concept of interpretation itself has become the source for controversy. The more philosophy and the interpretive disciplines proclaim the importance of interpretation in all of inquiry, the less there is agreement about what it is, what interpretive practices presuppose, and how to judge interpretive successes and failures. (Bohman, Hiley & Shusterman 1991, p. 1)

The demise of positivism was marked not only by changes in philosophy, but also by shifts in other disciplines, like sociology, and the growth of new disciplines. Significant among these is the recognition of social and cultural characteristics in understanding science, generally in the field of the sociology of science (henceforth SS) and a number of emergent and inter-related fields, principally STS and the sociology of scientific knowledge (SSK) (Callon 1995). Perhaps even more than in philosophy, a trend towards intersections of approaches has been noted in sociological studies of science and technology (Bowden 1995; Edge 1995):

Cross-cultural comparisons of knowledge and technology systems were a significant feature of STS studies during the 1960s and 1970s (Finnegan & Horton 1973; Goody 1977; Hollis & Lukes 1982; Horton 1967; Wilson 1977) but ceased to be an active site of STS work during the 1980s. This retreat from cross-cultural studies is currently being reversed as fresh insights are gained from the intersections of the social study of science with anthropology, postmodernism, feminism, postcolonialism, literary theory, geography, and environmentalism. (Watson-Verran & Turnbull 1995, p. 115)

There are viewpoints also from other fields, such as linguistics, policy studies, anthropology and psychology, and there are similarities and differences both within and between each of these fields such that it is possible to discern the emergence of some general characterisations of science that can derive from more than one intellectual tradition or field.

Acknowledging the contribution of multiple viewpoints may be interpreted as a reflection of a postmodern sensibility. Certainly the lack of a single received view in metascience, or even within either HPS or STS, is consistent with this notion. Following this line of argument, the present thesis may be considered to represent some sort of post-postmodern sensibility, that recognises the insights of multiple perspectives, but also
recognises a pragmatic reality of having to make decisions about devising a science curriculum and satisfying curriculum stakeholders.

3. The relationships between the dimension and the other dimensions

Section 3 of each companion chapter addresses the interactions of the dimensions. A significant part of the argument proposed in this thesis is that the six dimensions are interactive, that is, science is invariably characterised by several or all of the dimensions in combination. The dedication of a chapter to each dimension is simply an analytical device to explicate each of the proposed dimensions, but in so doing artificially isolates them. Therefore each dedicated companion chapter includes this section to give some examples of these interrelationships. Section 3 in each of the six companion chapters does not deal with all possible combinations and relationships, which is an impossible task. It merely mentions examples where some characterisation of science is made using more than one dimension.

4. Conclusions for use in curriculum theorising

Section 4 of each companion chapter addresses the implications of the analysis for the science curriculum. The present thesis is not a thesis in the history, philosophy and sociology of science, although much of it deals with those literatures and in Appendix B provides considerable metascientific argument to illustrate the scope and cogency of the dimensions. It seeks to map the fields of metascience in order to better inform the characterisation of science in the school curriculum. Therefore each of the companion chapters on the dimensions closes with this section, which draws from the preceding discussion issues for the school curriculum. These issues are taken up in the concluding chapter to synthesise a position for the curriculum.

5. The order of the six companion chapters

Finally, something must be said about the order chosen to present the six companion chapters, bearing in mind that each presents a dimension of characterising science, together
with discussion of its implication for the curriculum. To some extent the choice of order is arbitrary: it does not imply a necessary and logical priority or sequence, and could have been varied in order to make different emphases. This applies both to the characterisation of science and its implications for the curriculum.

To address first the characterisation of science, it was tempting to present the chapters on knowledge and activity first. These, after all, are the traditional and common categories of characterisation, and are what most readers would expect. Because of this, they were the first categories identified in the semantic analysis. However, the present thesis argues that other categories of meaning are also used in characterisations of science, sometimes explicitly, but frequently implicitly and embedded in the text. To show how they are used to add meaning to knowledge and activity would mean that the argument would have to be diverted to explain these additional arguments. This strategy was rejected because (1) it made the argument unnecessarily complex and hard to follow, and (2) this complexity did not make clear the role of each category or dimension. The chapter on belief system argues that elements of a belief system, such as assumptions, criteria for judgement, perspective and values, are logically prior to substantive beliefs (mostly the knowledge content) and appropriate activities. This is the reason for knowledge and activity being the most familiar dimensions - they are the explicit elements of the belief system, but they cannot be understood fully without the implicit elements. Thus it will ultimately help to read about belief systems early on.

The chapter on context is also addressed early because questions of context address some fundamental issues of characterising science, which is the central concern of the present thesis. First, the question of internalist and externalist views, although seen as declining in importance in some metascientific views, remains a significant issue for the development of the science curriculum. Secondly, the question of essentialist versus constructivist characterisations of science is significant for the science curriculum, because curriculum stakeholders frequently adopt some particular essentialist position apparently unaware of the implications of taking such a position. Thirdly, boundary work - studies of the boundaries between what is accepted as science or not - also suggest that curriculum
stakeholders engage in boundary work without realising the implications of taking particular stands. These are important issues to raise early on in the thesis, not just because they highlight arguments used in characterising science but because they raise issues that affect the interpretation of the metascientific literature generally. For these reasons, the chapter on context is presented first, and belief system second. Conversely, activity and knowledge, being the most familiar dimensions for most readers, are presented last so that they can be informed by the arguments in the preceding chapters.

As for the curriculum implications, the argument is constructed slightly differently. Section 4 of each companion chapter presents the curriculum implications arising from the particular dimension, but some curriculum arguments apply to all dimensions. For example, a central theme that is developed and progressively reinforced is that a general science education should make students, and hence our future scientists, technicians, and citizens generally, aware of the strengths and limitations of science in the increasingly scientific nature of western societies. To fail to understand how and why science works, and to appreciate different insights from various views of science, is to limit both the rationale for the very inclusion of science in the school curriculum, and reduce the justification for scientific belief by scientists working in their field and citizens alike (who, of course, include scientists). To avoid repetition of general arguments such as these in every companion chapter, therefore, the discussion of curriculum implications develops across the six and some general issues are addressed in the concluding chapter. This is not done to imply some significance in the order of dimensions for the curriculum; it simply follows the decisions about ordering the chapters, discussed above, but develops a curriculum argument in successive chapters. Thus, while the dimensions of science characterisation are presented so that in principle they could be read in any order, the theorising about the curriculum builds progressively in successive chapters.

Finally, it must be remembered that the separation of the dimensions into six separate chapters is only an analytical device to make explicit various arguments made about the nature of science, and to reduce the complexity of these arguments. As mentioned above, section 3 of each of the companion chapters, and the concluding chapter, are intended to
show that the literature uses combinations of these dimensions - that is, makes multidimensional characterisations - and that the complexities of characterisations can be simplified by identifying the dimensions or categories used.
Chapter 6

CONTEXT

Context, as in the circumstances surrounding a situation or event, or the parts of a discourse connected with units of text, is a necessary, but not sufficient, dimension of science.

Introduction

This chapter comprises an argument that context is a necessary, but not sufficient, dimension of science. Context is defined broadly, as the circumstances of, or the influence of one or more elements on, any particular element of science:

1. the parts of a discourse or writing that precede or follow, and are directly connected with, a given passage or word, [and]
2. the circumstances or facts that surround a particular situation, event, etc. (The Macquarie Dictionary).

It is the second meaning that is used in the present discussion, although as will be shown, it is interpreted broadly here. The first meaning may be taken to apply in the more restricted sense of a linguistic understanding of scientific and metascientific discourse.

The argument is that context is a necessary dimension of science in that characterisations in the metascientific literature are incomplete without it, and it does not reduce to any of the other dimensions, i.e. its omission is not covered by any of the other dimensions. It is not a sufficient dimension of science in that it does not completely characterise science. Where science is characterised in the literature by context, usually it is characterised also by one or more of the other dimensions of science: knowledge, purpose, activity, structure and belief system. These other dimensions may be used in explicating scientific context, and scientific context may be used in explicating the other dimensions.

One of the lingering influences of the positivist Received View (see discussion in chapter 5) is a widespread belief that science is acontextual: that scientific results are independent of where, when and by whom the science is done. A consequence of this
view is that the term context simply means the context in which science takes place, as represented in this Venn diagram:

In this sense, context might be taken to be an industry or government funding body, or legislation controlling the use of animals in laboratories, or society as a whole: that is, context means the organisations or structures that affect science, but are not actually science itself. This chapter will argue that such a view is only one of many views about context and science. Even to argue that context does not refer to science itself - that science is acontextual - is still to characterise science partly by context, a view that nevertheless relies on science being characterised by particular notions of context, like an intellectual tradition, specially trained personnel and specially equipped facilities. However, as just noted, many views argue that context characterises science just as strongly as other dimensions like activity or knowledge: that science is fundamentally shaped and its outcomes determined by funding arrangements, interpersonal networks, the state of equipment development, the available ideas, the motivations of scientists, the targeting of funding, and so forth. This is not represented neatly by a Venn diagram like the one above. Better would be some sort of representation of multiple dimensions along these lines:
This is quite a different idea of context and science, although it subsumes the earlier one, as this chapter will discuss at some length.

There is in particular considerable metascientific debate about whether science comprises only concepts and the methods by which we develop them, or whether science is more than this. The former view, which approximates the *internalist* view in the literature, essentially acknowledges an intellectual or cognitive context only: the context of ideas that gives meaning to other ideas. This view is strongly held. For example, the positivist RV acknowledged as scientific only that which could be rationally reconstructed. Thus the texts typically used in secondary or tertiary level courses of chemistry, physics or biology, are concerned only with a framework of concepts, propositions, laws and theories, i.e. the cognitive content. Ideas and propositions are generated, tested empirically and debated in terms of their cognitive merit. In this view, if science is done ‘properly’, a scientific claim can and should be examined regardless of its social, personal or other non-cognitive contexts. Thus the strength of science is that it is characterised by only its intellectual context and is in other respects acontextual. Against this is the latter view, which approximates *externalist* views in the literature. It holds that science cannot be understood by its conceptual framework and logical arguments alone: that a range of other contexts also characterise science, such as personal, social, economic, political and other factors. That is, science cannot be understood without considering the broader range of contexts. Much of this chapter is devoted to addressing this issue, firstly because it represents significant and vigorous debates in the literature which should be covered in this review, and secondly because it represents fundamental disagreements about the nature of science.

As with each of the companion chapters, the present chapter will make selective use of these accounts only. In so doing it will attempt to strike a balance between including sufficient detail to construct the argument and not repeating the detail available in the literature.
The argument in this chapter comprises four parts, as set out in the introduction to the six companion chapters:

1) evidence from the analysis of the summary statements;
2) evidence from argument in the metascientific literature;
3) the relationships between the dimension context and the other dimensions;
4) conclusions for use in theorising about the science curriculum.
1. Evidence from the summary statements

*Context as a partial characteristic of science is indicated in the summary statements from the metascientific literature collected in Figure A.1*

The collection of classes (in Table A.6) and text units from the differentiae (column five of Table A.9, headed Context), collectively indicate that any particular aspect or circumstance of science is characterised partly by surrounding factors. As with the other dimensions, this category of characterisation was constructed from a semantic analysis of many metascientific sources. Thus it includes a wider range of viewpoints than do many individual positions in the literature. In particular, we have noted in chapter 4 that some summary statements use tradition to mean ideas, as in an intellectual tradition, while others use it to mean to cultural or social norms, as in a tradition within a social or sub-cultural group. These interpretations correspond to internalist and externalist positions, respectively. The very identification of different views of what constitutes legitimate contexts for science, a debate discussed below in Appendix B.1.3 below, uses and therefore legitimises context as a dimension of characterisation.

Chapter 4 also mentions the lack of reference, in many of the summary statements, to any sort of context. Even though the summary statements are extracts from larger arguments, the surrounding arguments of many statements do not mention context, and other statements dismiss it. These writings, therefore, put a view that science is acontextual, either explicitly, or implicitly by omitting reference to context. This is a significant issue in characterising science and is addressed below in the discussion of internalism and externalism. To emphasise the point, the very omission of reference to when, where or by whom science occurs implies that the science described is the same no matter whether done, for example, in Europe or south east Asia, under capitalist or socialist governments, or in times of war or peace. Summary statements characterising science as acontextual include entries from general dictionaries (1 and 80) and 2, 3, 7, 8, 9, 10, 11, 16, 17 and 19 from the first twenty.
However, many other summary statements do refer to context, of various sorts and to varying degrees. Notions of context include the following from just the first twenty statements, to indicate that the notion of context is used in various ways:

(a) There is a notion of an historical context, meaning that we can identify a tradition of science over time, and that the science of today has not formed from disconnected contemporary events, but from antecedents which can be traced back through time. Thus there are text units which indicate, explicitly or implicitly, a temporal or historical context:

- *traditionally studied* (4)
- *that has evolved* (13)
- *which takes place in a particular sort of tradition* (20)

(b) There is a notion of science being associated with *people* - it has a human context. It is not part of the non-living environment, like the wind or rain, nor does it arise from the actions of non-human living things, and nor does it exist independently of humans. It is done by, and done for, humans, as the following text units state or imply:

- *[as] a domain of human [knowledge]* (5)
- *[as done by] scientists* (5)
- *[as one among] other fields of human endeavour* (5)
- *[as a] human activity* (13)
- *[as concerning] our place [in] the world* (14)
- *[as] a creation of the human mind* (15)
- *[as comprising] the producers (researchers)* (18)

(c) Science is sometimes characterised or portrayed in the context of other tasks, uses and purposes, which can be termed a utilitarian context:

- *[that] can in fact be used in a variety of ways* (14)
- *[as] designed for educating or accrediting scientists* (14)
- *[as] protecting the interests of the scientific estate* (14)
- *[as serving] to maintain and to perpetuate structures and*
patterns of social domination and subordination  

- [as comprising] the products ... and interesses of these products

(d) Science is sometimes characterised or portrayed in the context of a tradition or accepted practices, beliefs, purposes, structures or knowledges. This can be termed a traditional context:

- [as one among] other fields of human endeavour
- distinct from either tradition or authority
- [as] essentially centred in a paradigm
- which takes place in a particular sort of tradition

(e) Science is sometimes characterised or portrayed in terms of groups of people, which may be small research teams, larger groups such as sub-cultures within society, or the general society as a whole. This can be termed a social context:

- which itself forms part of a larger system: science in society

These examples are given simply to illustrate that even within the first twenty summary statements the general notion of context applies in various ways. Note that the five loose clusters (a) to (e) above are not discrete categories, because some statements fit in more than one. Summary statement 21 itself describes how views of science in different contexts have different conceptions of what is legitimate scientific context. Thus, in Anglo-American parlance, science is characterised as non-societal, non-cultural, whereas in many countries including France, Germany, Italy, Russia and Japan science refers to general scholarship that may therefore include societal and cultural factors. Even these five loose clusters are sufficient to show some uses of context in characterising science, and to argue for a broad interpretation of context as a category or dimension of characterisation.
2. Argument from the metascientific literature

Debates in the metascientific literature address many aspects of context in science, which again supports a broad interpretation of scientific context. Appendix B.1 outlines the variations, implications and subtleties of several of these debates to indicate the scope of the ways in which science is characterised partly by context. The arguments presented in Appendix B.1 are briefly as follows.

B.1.1 Current metascientific views with respect to context

Different metascientific views characterise science differently by intellectual (cognitive), psychological, social and ontological contexts.

B.1.2 Boundary concerns

A central issue in much characterisation of science is how and where one constructs the ‘boundaries’ between what is regarded as science and non-science.

B.1.3 Context as being ‘Internal’ and ‘External’

Another central issue in characterising science, arising from the enduring influence of the positivist Received View (RV), is whether science is characterised only by its intellectual or cognitive context (internalism) - the ideas of science and received knowledge - or whether also or instead it is characterised by other contexts such as social and psychological contexts.

B.1.4 Historical contexts of science

Science is sometimes represented by its characteristic history.

B.1.5 Intellectual contexts of science

Science is sometimes represented by its characteristic ideas and knowledge.

B.1.6 Socio-cultural contexts of science
Science is sometimes represented by its characteristic social and cultural contexts, both in the sense of science being part of a larger socio-cultural context, and of sub-cultures of sciences.

**B.1.7 Human contexts of science**

Science is sometimes represented by its characteristic human contexts, such as characteristic traits of scientists, psychological factors, human elements in scientific activities, and personality.

**B.1.8 Organisational contexts**

Science is sometimes represented by its characteristic social organisations, like research units and university faculties, which correspond and interact in various ways with knowledge structures.

**B.1.9 Physical contexts of science**

Science is sometimes represented by its characteristic physical contexts, like artefacts and locations, notably laboratories.

This is not intended as an exhaustive list, but merely one which addresses significant themes in characterisations of science in the literature.

*Context as a necessary dimension of science*

The argument to this point of the chapter, including Appendix B.1, has shown a variety of ways that the metascientific literature characterises or portrays science in terms of context. That is, science is characterised by, or can be identified by, for example: its history; its ideas and concepts as they stand relative to other ideas and concepts; particular groups of people and organisations and how they stand in relation to other groups; particular individuals with particular skills and dispositions; particular locations and artefacts; and by the efforts of individuals and groups to define the boundaries between science and other human enterprises. The argument that context is a necessary dimension does not rest on such a list in itself, but on the arguments summarised by the list: not only
do metascientific arguments typically appeal to notions of context, but many accounts hold that contextual factors actually constitute science. In either case the argument fails if context is removed. Further, the literature provides a variety of accounts of, and disputes over, these contextual aspects. To understand this variety one must be familiar with at least some of the major positions. To recognise only a single position, when there exists a substantial academic literature of debate, is to fail to understand that there may be plausible alternatives, to miss insights provided by alternatives, and especially to be unable to defend a particular view from the attack of other views. One cannot appreciate the certainty or strength of a particular view without appreciating the strength of alternative arguments. It follows that to understand science, one must: first, understand the contribution of contextual factors to the nature of science; secondly, appreciate that accounts of this contribution differ; and thirdly, appreciate the insights of some alternative characterisations.
3. The relationships between the dimension of context and the other dimensions

While context is a necessary dimension of characterisation, as argued in section 2 above, it is not sufficient to characterise science. This is because context is typically used in combination with other dimensions of characterisation, namely knowledge, activity, structure, purpose and belief system. We have referred to these other dimensions throughout this chapter, but rarely explicitly and at best only hinting at relationships between combinations of the dimension. This is because the present chapter seeks to draw the reader’s attention to context as a dimension of characterisation. This will instead show how context is used as a dimension in combination, by analysing some multidimensional characterisations of science that include context.

Context and structure

In formulating the dimension context, considerable thought was given to whether it included or subsumed the dimension structure. Support for conflating the two is given by The New Webster Encyclopedic Dictionary of the English Language (1971) which includes the following meanings for these terms:

Context:
The manner of interweaving several parts into one body; the disposition and union of the constituent parts of a thing with respect to each other; constitution;
Structure:
The arrangement of the parts in a whole (the structure of a sentence, rock of a columnar structure); manner or mode of organisation; mode in which different organs or parts are arranged.

This does not make a clear difference between the two. A clear distinction is made by the equivalent entries in the Macquarie Dictionary:

Context:
2. the circumstances of facts that surround a particular situation, event, etc.
Structure:
1. The mode of building, construction or organisation; arrangement of parts, elements or constituents.
2. Something built or constructed ...
3. A complex system considered from the point of view of the whole rather than of any single part: the structure of modern science.
4. Anything composed of parts arranged together in some way; an organisation.
Thus in some sense of these terms, the component parts of a structure form a context for each other. On this basis the notion of structure could be subsumed under context: it could be meaningful to speak of the structural or organisational context.

However, there are several arguments opposing this view, and it remains up to the author to make the case for as many or as few categories as are plausible: the categories of characterisation proposed in this thesis are, after all, constructions or inventions. These arguments include the following. (1) The categories of meaning identified in Appendix A.1, upon which the proposed categories of characterisation are based, are meaningfully distinguished and derived from the data. (2) Many terms in Appendix A.1 are used to indicate a context but not a structure, or structure without recourse to the concept of context. (3) While there is a sense that structure can be considered part of the context, so too can the belief system, concepts and activities be considered part of the context. That is, just about anything can be considered to be part of the context of something else, in which sense context is not a useful category. Some views in the literature do interpret science primarily in terms of context, but even so (and the present thesis has disallowed recourse to a single viewpoint from the literature) it results in a single category of characterisation which would then have to be further categorised to be useful. Equally, some views of science see it as essentially a belief system or essentially knowledge. (4) A close relationship between these two categories of characterisation simply demonstrates again the nature of the proposed dimensions: they are not proposed as separate entities like six slices of a pie, but six dimensions of meaning. That is, they label six ways in which scholars view science or six points of focus for analysis of science. (5) Having the two categories ensures that all elements of characterisation are categorised, whereas conflating the two may create too coarse an analysis. The judgement in the present thesis is that the justification for separate categories of context and structure is better made than for conflating them, in terms of the purpose of the thesis. That is, they are more useful if considered distinctly, for the purpose of the present thesis.

The juxtaposition of context and structure is nicely illustrated by Abbott’s (1988) study, The System of Professions, given by Gieryn as background to his discussion of
boundary-work (Gieryn 1995, pp. 409-11). The notion of a profession is clearly one of structure, system or organisation, which Abbott characterises in terms of a range of contexts:

Abbott rejects the idea that the development of a profession is independent of the practices and claims of other professions or differently organised occupations. Instead, the history of one profession is best understood through its contests with other professions for jurisdictional control over tasks - the professions together constitute a system that is the proper unit of analysis for sociological theorising. Abbott focuses on interprofessional competitions created when more than one occupational group lays claim to the legitimate provision of three tasks - diagnosis, inferential interpretation, and treatment of problems. The book offers a structural model (tempered by sensitivity to historical contingencies and actors’ initiative) to explain the causes of jurisdictional contests among professions, the mechanisms through which one or another side gains advantage, and the variety of settlement patterns that restore the system to equilibrium. The boundary problem is ubiquitous: How do tasks and competencies map onto the ecology or geography of professions and their abutting occupations? (Gieryn 1995, p. 409)

Abbott identifies a set of contextual factors that determine the nature and outcomes of these jurisdictional contests: the arenas in which they are found, what brings the contests to a head, how the contests are settled, the strategies used to make the arguments, and patterns of settlement. Briefly, jurisdictional contests are fought in three arenas: the legal arena of courts and legislature, the public arena of public opinion and media representation, and the work site of professional activity. These contests do not come to a head randomly or from the greed of expanding professions, but through individual and corporate intentions which the present thesis interprets as purposes. These intentions are influenced by structural and cultural factors, notably changes in technology or organisation, co-opting of professions by external groups, changing values used to legitimate boundary claims, and the growth of modern universities, which bestow professional credentials. Demarcation contests are argued using particular rhetorical strategies: reduction of a task to one already within the boundary, using metaphor to argue the similarity of a task to one within the boundary, and creating a gradient to argue that a complex problem translates into milder, solvable problems. Lastly, there are distinct patterns of settling boundary disputes: one profession wins full jurisdiction (which entails the other(s) winning no jurisdiction), subordination (meaning the delegation of minor tasks to other professions or non-professions, as in the delegation by physicians of bedside care to nurses), division of labour between professions (as with engineers and
architects), *intellectual control* (meaning splitting the abstract from the practical), *advisory control* (where one profession advises within the boundary of another, as in science-law), and *clientele differentiation*, where different professions do the same work but for different clients or markets. Considering the case studies given by Gieryn as examples of boundary work, Abbott's focus on jurisdictional competition between professions is useful in interpreting demarcation issues of science. Gieryn uses examples of all three arenas, catalysts for contests, settlement of contests, rhetorical strategies and patterns of settlement.

Furthermore, in terms of the present thesis, we can identify in Abbott's account appeals to all six dimensions - context, structure, belief system, activity, purpose and knowledge - in characterising professions. The interrelationship of dimensions, of course, tends to be masked by the discussion of metascientific views in Appendix B.1, because the argument here is presented in order to highlight the use of a particular dimension, namely *context*. It is worthwhile reinforcing in this section that the six dimensions are identified and proposed as an interactive set of six. That is, embedded in the language of a wide range of metascientific discussions are several of, or all six, dimensions in combination.

*Context and belief system*

Context and belief system are inter-related in many ways. The emergence of an historicist characterisation of science in the Enlightenment, mentioned above, entailed assumptions that science exhibited certain uniformities that persisted historically:

> [The Enlightenment] laid down a series of assumptions concerning science and its historical existence which have been so influential that *all* Western historians of science have been formed within them. This holds equally whether historians have been persuaded of the Enlightenment's commitments, or whether they have attempted to modify them. (Christie 1990, p. 7)

Indeed, it is the 'universal assumption that modern science has some simply graspable defining feature' which Schuster (1990, p. 221) holds to be responsible for the lack of resolution of externalism/internalism (e/i) and revolution/continuity debates, which have attempted to identify and interpret such universal features.
Specific instances of claimed interaction of context and belief system abound. For example, the notion of scientific laws in western European science has been interpreted as arising from the Christian belief that the cosmos is controlled by a law-giving God. In China, this belief was not shared by the Mohists or the Logicians, but Ronan (1982) has interpreted it as similar to the belief system of the group known as the Legalists, as discussed in Appendix B.2. Ronan characterises the (post-Legalist) Chinese and European approaches as differing based on the belief systems arising in different cultural contexts. The structure of laws of Nature in Western European science is explained in terms of Western European beliefs that everything - humans and their environment - operated because they were guided by ‘divinely ordained laws’ given by powerful, ‘personal guiding deities’. However, he characterises Chinese natural philosophy by a belief that the cosmos was an organism, and behaved as it did, not because it obeyed laws, but because of its nature as an organism.

Another example of interaction between elements of a belief system and context is the notion of science as a subculture characterised by shared norms, where norms are argued in the present thesis as elements of a belief system. The best known example is Robert Merton’s (1942, 1967), that characterises science as a social activity arising from four institutional norms or imperatives:

The ethos of science is that affectively toned complex of values and norms which is held to be binding on the man [sic] of science. The norms are expressed in the form of prescriptions, procriptions, preferences and permissions. They are legitimatised in terms of institutional values. These imperatives, transmitted by precept and example and reinforced by sanctions are in varying degrees internalised by the scientist, thus fashioning his[her] scientific conscious ... (Merton 1942, in Barnes 1972, pp. 66-7)

Merton argued that, historically, the institutionalisation of Western European science is characterised partly by its wider social context. Prior to becoming a widely accepted social institution, science was not accepted as valuable in its own right, as it was later. In seventeenth century England, though not necessarily in other societies, the values to which science protagonists appealed were the values and practices of ‘ascetic Protestantism’:

In his most recent defence of the Merton thesis, Merton (1984) examines the thesis at three levels of theoretical abstraction. The sociohistorical version is that
ascetic Protestantism helped to ‘motivate and canalise the activities of men in the direction of experimental science.’ The middle-range hypothesis is that the development of science, like the development of any institution, had to be supported by group values. At the most general and abstract level, the hypothesis is that the interests, motivations, and behaviours in any given institutional sphere - such as religion or economy - are interdependent with the interests, motivations, and behaviour in other institutional spheres - such as science. No matter how distinct and autonomous institutional spheres seem to be, they are linked through the multiple statuses and roles of given individuals. (Restivo 1995, pp. 97-8)

Restivo notes that there was debate, following the original formulation of Merton’s thesis, as to whether Puritanism followed science or science followed Puritanism. More recent analyses suggest the parallel development of Puritanism, science and capitalism, each reflecting, in the terminology of the present thesis, purpose (roles and purposes), belief system (values), and context (roles, and institutional, ecological and organisational contexts).

An interesting example of interplay between context and other dimensions of characterisation is Watson-Verran and Turnbull’s analysis of the overlap between two knowledge systems, using the example of Watson’s work with the Yolngu Aboriginal Australian community (Watson-Verran and Turnbull 1995, pp. 131-6). This is ‘work within the historically layered contestation between white Australia and Aboriginal Australia’ (p. 131). Both these traditions contest the notion of a dual system of knowledge production, although contemporary Aboriginal cultures are more likely to accept that there is a ‘critical and interpretive core of all knowledge’. Significantly, this is explained by their status as ‘subjugated knowledges’, and not because of the inherent rationality of Western European science. Yolngu knowledge is characterised by a fundamentally different language and conceptual structure to that of Western science: the former entails entities and designates relations between them - a formalised recursion of relationships - whereas the latter designates relations between spatiotemporal entities - a formalised recursion of tallying or number. Western knowledge sees Nature, society and knowledge as distinct: for example, knowledge is a representation of reality. Yolngu knowledge does not make this distinction, and is therefore antirepresentationalist, and may be characterised as idealist (p. 134). In exploring ways to merge the two, the project sought characteristics that could be assimilated by each side:
In this process Yolngu look for and emphasise metaphor in Western knowledge. Science looks for and emphasises codification and develops a grid in which two systems can be seen in ratio. (Watson-Verran & Turnbull 1995, p. 124)

The researchers in this process sought to be sensitive to both traditions of knowledge, which entail both implicit and explicit characterisations:

Having learned how to see these analogies and understand things in new ways, we are answerable for what we do next. If we are to hope for transformations of systems of knowledge, for the reconstruction of worlds less organised by axes of domination, we cannot present our claims to new knowledge as universal claims. Nor can we treat their mobilisation in the dual knowledge production systems within which we work as unproblematic, using stabilised assemblages as though they were transparent technologies. In working through the dual sets of devices and strategies whereby claims are mobilised from Yirrkala, the site of our work, we must 'focus up' the forms of association, the values, and the politics embodied in the products and the processes of our work. (Watson-Verran & Turnbull 1995, p. 136)

If we now seek to identify the complete characterisation, rather than highlight the use of a particular dimension, we find in the passage above all six elements of characterisation used together. Thus Watson-Verran and Turnbull characterise science by structure (system, assemblages, sets and forms of association); by knowledge (systems of knowledge, new knowledge and knowledge production systems); by context in the senses of one among many (systems and not system), socio-cultural (implicitly the Yolngu and European Australians) and physical-spatial (Yirrkala, the site of our work); by activity (production, working through ... devices and strategies, claims are mobilised, and the processes of our work); by purpose (strategies); and by belief system (implicit in the whole passage, explicit in values and politics embodied in ...).

Redner's characterisation of twentieth century science

Redner's (1987) interpretive history of science makes strong use of multiple dimensions in combination in its characterisation of science. Redner characterised the history of (western) science by three major epochs, where the third, which he calls World science, emerged only during the twentieth century:

In the West there have already been two major scientific epochs: the ancient-mediaeval and the post-Renaissance. The first might be called Aristotelian-Ptolemaic science in honour of its outstanding theorists; along similar lines the second might be referred to as Newtonian-Einsteinian science, and I have called it Classical science for short. Each of these long-lasting epochs had its own relatively distinct internal phases and divisions, which might be listed in the
following stages. Aristotelian-Ptolemaic science began with a Greek phase which culminated in the achievements of the Museum of Alexandria, followed by a more pedestrian Roman phase; subsequent to the fall of the ancient classical world, it went through at lest three successive revivals and transformations, which might be called Arab-mediaeval, Christian-mediaeval and Renaissance, but basically it remained the same kind of speculative science throughout. The first epochal transition took place only with the Scientific Revolution of the seventeenth century, which established Newtonian science in total opposition to the previous Aristotelian-Ptolemaic science. This epoch might in turn be divided into two major phases: the first from the formation of the scientific academies of the Royal Society till the French Revolution and the second from the new French Grandes Ecoles and the German universities till the onset of the Second World War. (Redner 1987, pp. 19-20)

Drawing on a wide range of sources, Redner characterised the differences between these epochs not just by different knowledge content, as in descriptive histories, but by different criteria of what constitutes knowledge and what the knowledge means. The present thesis interprets this as characterising science mainly by context (history), knowledge, and belief system (such as criteria for judgements).

Thus, in what Redner called Ancient-Mediaeval science, knowledge was largely conceptual or 'essentialist'. It was set securely and metaphysically ordered within a philosophical system. This is exemplified in the Ptolemaic cosmology of a closed, finite, ordered and hierarchically structured world with the Earth at its centre, nested in a hierarchy of concentric spheres:

By this world view every piece of knowledge had its assigned place in the overall scheme, and anything that could not be fitted in was not considered true or was not even counted as knowledge (theoria) as distinct from mere opinion (doxa). Knowledge was essential, necessary, certain, perfect, eternal and divine; opinion was accidental, contingent, corrupt, historical and worldly. (Redner 1987, p. 20)

The Classical science epoch began with the rejection of the earlier world view, in the Scientific Revolution. Redner characterises Classical science as producing knowledge of how things related and were bound by laws, rather than with what the essential nature of things was, as in ancient science. The present thesis interprets this as resulting from a change in purpose or aim, and belief system. Classical science assumed the universe to be infinite and the same everywhere, with no centre, no boundary and no hierarchy of rankings. Laws, therefore, applied equally everywhere:

The overall intellectual quest of Classical science can be characterised as a search for fundamental simplicity, universality and total determinism. (Redner 1987, p. 23)
The relationships sought were mathematical, deduced rationally from first principles and experimentally tested (activity). The quest for fundamental simplicity expressed in general laws (structure), marks Classical science as tending to be reductionist. With an infinite universe, in principle the search for knowledge was infinite also because an unlimited Nature implied an unlimited knowledge of it. In turn, this fostered a particular and enduring view of science itself:

This conceptualisation made possible the idea of an endless progress of science - an idea that is itself historically relative ... (Redner 1987, p. 20).

Many histories interpret Einstein’s general relativity theory as the beginning of a new epoch, but Redner marks it as part of the culmination of Classical science, that made possible the third epoch, contemporary World science. General relativity presented a different cosmology to Newton’s, in which space is curved and bounded and therefore endless but finite; what Newton had proposed as gravity or action at a distance could now be reinterpreted as a function of Einsteinian space. However, Einstein was wedded to the Classical epistemology of deterministic cause and effect, hence his often-cited remark that ‘God does not play dice’. For Redner, citing Prigogine and others, this characterises a difference between epochs: Bohr’s principle of complementarity and Heisenberg’s principle of uncertainty entailed discontinuities, such as quantum jumps, and indeterminacy at micro levels that were fundamentally incompatible with Classical science. Thus Classical science is characterised by simplicity, reversibility and determinism, in its presuppositions about Nature and its approach to this Nature (Redner p. 28). These are beliefs, assumptions and criteria, which the present thesis interprets as elements of a belief system.

On the other hand, Redner characterises World science by technification, formalisation, abstraction, problem-solving and finalisation (pp. 60ff). The elements of these characteristics were present in the nineteenth century, but they did not coalesce into ‘a dominant system of sciences’ until well into the twentieth century (p. 63). Briefly, technification is a process by which techniques tend to replace traditional practices of
research. *Formalisation*, *abstraction* and *problem-solving* often accompany technification, although they can arise without it, and are associated with a tendency to introduce mathematical techniques. *Formalisation* is the tendency to draw together quantified data into relations, laws and eventually a systematic and formal theory. *Abstraction* results from the selection of ideal or abstract subjects from the more complex reality so that they suit mathematical description. *Problem-solving* arises because mathematical, axiomatic science couches its questions as problems for which there are particular solutions. *Finalisation* arises as the natural and only outcome for such axiomatic problems, since the research does not provide any direction from within itself.

Redner argues that these characteristics reinforce both the authority structures of World science, and its suitability for technical application. That is, external contextual factors fundamentally characterise World science, regardless of any internal, intellectual context. Thus Redner argues that the change from Classical to World science is not marked by particular and outstanding intellectual revolutions, but by changes in structure, organisation and ways of working which nonetheless have resulted in logical contributions of individuals that are rarely distinct. In themselves, these changes could be dismissed as contextual changes to Classical science, but Redner argues that they result in a different kind of knowledge to that of Classical science, possibly analogous to the difference between Classical and Aristotelian knowledge. The different forms of knowledge - Ancient, Classical and World - are different but not incommensurable, since the later forms grew out of the earlier forms. This constitutes a scientific tradition. The difference between World science and Classical science is characterised by more than the instrumental and organisational changes. The reductionist character of Classical science, most notably in the logical positivists, meant that it failed to deal with the organised complexity of Nature: the properties of water, for example, cannot be reduced to

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1 Redner characterises technified science as science in which the role of technology is changed from extending the human faculties, as with the microscope and telescope, to actually generating the data being investigated, as with the cyclotron and computer. With the cyclotron, for example, we do not 'see' sub-atomic particles in the same sense as we 'see' with a microscope, because for the most part, he argues, the cyclotron generates the very particles it is being used to investigate. Part of the theory of the particles is the theory of how the machine works, and without such a theory the data are meaningless (Redner 1987, p. 68).
properties of oxygen and hydrogen within Classical science. World sciences, on the other hand, are complex and address complexities, although not all contemporary sciences are Big science:

Contemporary World sciences, by contrast, have tended to be applied to precisely such complexities. Complexity is a feature of the objects they deal with, the methods with which they work and the way they are organised to utilise such methods. Thus cognitively, instrumentally and organisationally the World sciences are complex and deal with complexity. This aspect is broadly understood for these science are commonly referred to as practising Big Science - though this formulation is not very accurate because not all contemporary sciences are Big Science. The term ‘Big Science’ is meant to reflect their organisational complexity; it tells us about their other dimensions. These might be indicated colloquially by saying that these sciences deal with Big Objects. (Redner 1987, p. 25)

To conclude the metascientific analysis in this chapter, characterisations of science often appeal to various notions of context, and typically in combination with other dimensions, as in the preceding examples. This has implications for science in the school curriculum, to which we now turn.
4. Conclusions for theorising about the science curriculum

This section will extend the argument, given above, that scientific context is an integral part of metascientific characterisations of science, to claim also that it should form part of school Science. This argument is based on several premises. First, the preceding argument in this chapter has shown that context is a necessary but not sufficient dimension of science in the metascientific literature. Second, the scope of scientific context is much broader than most individual characterisations of science address: to understand science it is necessary to understand, firstly, that science arises from a variety of contextual factors, and secondly, how these contexts shape science and different perceptions of it. Third, the traditional academic school science curriculum is overwhelmingly concerned with science knowledge content and certain activities - i.e. it is strongly internalist; this is well documented (see Matthews 1994). This characterisation of science is both incomplete and strongly contested in the literature. Such an incomplete characterisation renders improbable a general appreciation of how science works such as the educated citizen increasingly requires. Moreover, to fail to understand that a broader notion of context than simply the cognitive actually constitutes science, is to limit a rationale for the study of science, and reduces the justification of scientific belief. Also, it makes more difficult an appreciation of the special sense in which the scientific community understands scientific knowledge to be tentative yet authoritative. This section will argue that these claims apply both to the general science curriculum for all students, and to specialised curricula intended to cater for students with special needs, including those intending a career in science. Most of this argument is structured as a series of numbered paragraphs, which firstly summarise Appendix B.1, and secondly highlight the significance of context for the science curriculum.
I. Findings about the nature of science contexts from the review of the metascientific literature.

To the extent that there is a current (albeit complex) metascientific consensus, it is the agreement that there is no longer a single received view of science, and particularly here, that there is no single agreed view of scientific context. With the decline in metascientific influence of positivism, there is widespread but not universal metascientific agreement that the positivists’ rejection of all but intellectual context was mistaken. Accounts within the contemporary loose consensus recognise multiple notions of context, variously including psychological, socio-cultural and ontological contexts, for example. However, we have seen that positivism remains influential as a tendency of thought in the natural sciences generally, and is particularly influential in certain fields, such as behavioural psychology. For example, in their day to day work many scientists primarily address the cognitive context - the manipulation of scientific concepts and propositions that is the bread and butter of their work. Yet studies from a variety of perspectives show that this alone is inadequate to understand how and why decisions are made about science knowledge. This points to a general need to provide a richer notion of context in school science: clearly there is a need for students to become familiar with the cognitive context of science, but also to develop a broader understanding of its contexts, as will be developed below. These ideas can be summarised as follows.

There is a range of currently accepted views of science that characterise science by various notions of context.

a) For much of the twentieth century only the cognitive or intellectual context was subjected to any significant analysis and remains prominent in scientific practice, but as the sole context it does not withstand contemporary philosophical or sociological analysis.
b) The restriction of scientific context to only cognitive or intellectual characteristics remains a tendency of thought in the natural sciences generally, and an influential characterisation of science in certain fields, such as behavioural psychology.

c) The range of relative emphases on internal (cognitive or intellectual) and external (socio-cultural, political, economic, psychological and other) contexts is represented in externalist/internalist (e/i) debates.

d) Internalism characterises science knowledge as unique, rational and autonomous; externalism accommodates a wider context of factors that characterise and affect science that, except in extreme externalism, includes cognitive factors; each provides particular insights into science.

e) E/i debates are considered by some metascientists now to be passé and unproductive, but by others to have yet to be resolved; however, beyond this specialised field of expertise, such as among the majority of curriculum stakeholders, e/i issues remain contentious.

f) The present thesis accepts the position of some accounts (such as Morrell) that extreme e/i positions should be avoided except as examples of tendencies of thought or analysis.

g) Extreme internalism, concerning only the abstract logical and cognitive characteristics of scientific ideas, explains neither the working of science as a whole nor the development of many scientific ideas.

h) Extreme externalism, concerning sociocultural, political, technical, economic and military contexts of science, does not explain the cognitive criteria by which scientific ideas are formed and scrutinised.

Determining the context of the scientific and the non-scientific is described in the literature as boundary work

i) All fields, including science, are characterised by exercises in establishing the boundary between what is agreed as the field (in this case science) and what is not; this is called boundary work.
j) Boundary work has been characterised by Foucault as making the truth and power of the field, which in science can be interpreted as seeking to explain the cognitive authority of science.

k) This so-called boundary work either seeks to identify the essential characteristics by which science is uniquely and necessarily distinguished from non-science (essentialism), or to identify the ways in which people contend for, legitimate or challenge scientific authority (constructivism).

l) Essentialism assumes that there are characteristics that uniquely establish or demarcate science, and seeks to identify them: the major essentialist position in philosophy is given in Popper’s criterion of falsifiability; the major essentialist position in history is given in Kuhn’s paradigmatic consensus and problem-solving; in sociology, the major essentialist position is given in Merton’s four social norms of science, namely universalism, communism, disinterestedness and organised scepticism.

m) Essentialist approaches to boundary work are flawed because each is subject to telling criticisms: for each of them, examples in actual scientific practices show that they do not, and sometimes cannot, apply, except as ideals (aims or purposes) of science; in practice each seems to reduce to social negotiation of scientists and, sometimes, others.

n) Constructivism makes no essentialist assumptions, and instead seeks to understand the boundaries of science by describing boundary work in action: constructivist approaches have identified a range of boundary episodes in political, technological, social and other contexts.

o) The present thesis is an example of constructivist boundary work to the extent that it attempts to theorise about how the metascientific literature characterises science.

Science can be characterised by its intellectual context

p) The available ideas, beliefs and concepts constitute an intellectual context within which scientists, and others, work and think.
q) The intellectual context can be interpreted from several perspectives: as the currently accepted conceptual framework that partly characterises the normal science with a Kuhnian paradigm; as the long-standing divide between the science and arts communities of scholars (Snow’s ‘two cultures’); and as the auxiliary theories from which technical concepts such as auxiliary statements are drawn to support any particular theory (a notion that supports the influence of theory on observations).

r) The intellectual context - the available framework of concepts and understandings - is massive, and in many fields is rapidly increasing and changing; it is well beyond the total comprehension of any individual.

s) Because the intellectual context is subject to testing and revision, it is authoritative while at the same time dynamic and tentative.

*Science can be characterised by its historical contexts*

i) Modern science can be traced mainly through a western European tradition, which shows not only historical antecedents to present day science, but examples of the testing and rejection of ideas by which we characterise science.

u) Historians tend to emphasise either the continuity of the scientific tradition, or the discontinuity when significant ideas are superseded (hence terms like the Scientific Revolution); like most historical categories, each approach provides its own insights.

v) While many ideas and beliefs can be dated to the early Greeks, the roots of present day science date more clearly from the Scientific Revolution; many of its present characteristics date from the twentieth century, reflecting an increasing rate of change.

w) Traditional science histories have tended to be accounts of the individuals and ideas that were clear antecedents of current scientific knowledge and practice; they tend to ratify the successful revolutions and individuals and, because the characterise science as a progressive march, are called Whig histories.
x) Recent developments in historical analysis have criticised Whig histories as distorting the history of science, and point to the need to interpret historical events in their own terms; in this way, we can construct an understanding of why certain ideas rose and fell from favour.

y) Science histories show that not only has accepted knowledge changed over time, but also notions of what is accepted as truth and rationality.

*Science can be characterised in various ways by socio-cultural contexts*

z) Science can be characterised as a subculture that affects and is affected by society at large and other sub-cultures within society, such as religious, economic, political and military interests; distinctions, such as between science and technology, have become increasingly blurred, or, such as with the social, political and religious, increasingly contested.

aa) Science can be characterised by subcultures within it, which includes the notion of paradigms of thought and approach; subcultures within science are becoming increasingly differentiated by specialisation.

bb) The meanings of scientific phenomena are interpreted through a world-view or *Weltanschauungen*, which may arise from particular scientific and broader cultural contexts; it is the world-view or *Weltanschauungen* within which individuals and groups interpret or make meaning of phenomena.

cc) Feminist critiques characterise science by a masculine *Weltanschauungen*, in the sense that the metaphors used in making scientific explanations may arise from broader cultural contexts, such as masculine imagery.

dd) In recent decades, developments in fields such as history, sociology and anthropology have become increasingly critical of traditional methods of cross-cultural comparisons because these methods tend to leave unexamined the effect of western cultural beliefs and practices on both western and non-western natural philosophies; they question the meaningfulness of interpreting traditions from other, non-western, contexts from within a western context.
ee) In recent decades there has been increasing interest in the natural philosophies of other cultural traditions, both because of their intrinsic insights, and because of the insights they afford into western European science by way of comparison.

ff) Use of the term *science* in non-Western contexts is difficult because of these problems in cross-cultural comparisons; the present thesis uses a common alternative, the term *natural philosophies*.

gg) The western literature on the natural philosophies of non-western European cultures is relatively small, and often negligible, in comparison to the literature on western European science, so our relative understanding of different traditions is disproportionate.

**Science can be characterised by human contexts**

hh) Scientific progress can be characterised partly by the characteristics of individual scientists rather than groups; this has been recognised more in post-positivist accounts of science that seek to describe actual practices rather than reconstruct ideal practice in terms of logic and rationality.

ii) Popular characterisations of scientists tend to be stereotypic, notably in the mass media.

jj) The effect of such stereotypes on children's perception of science and career choices is well documented and generally thought to work against the interests of science.

kk) Individual characteristics of scientists include psychological attributes such as learning, cognition, personality, competition, ambition, incentive, motivation, interest and confidence.

ll) The individual characteristics of scientists provide more complete accounts of much of science as it is practiced than do abstract notions such as logic and rationality.

mm) Studies that focus on the individual cognition of scientists often provide psychological explanations of scientific discovery, such as a type of learning, a
gestalt shift, the interplay of psychological and social factors, or as a novel synthesis of concepts.

nn) Some studies of individual scientists address the roles of competition, ambition, incentive, motivation, interest, confidence, and the personality of the scientist, particularly as it contributes to the relative success of different scientists.

oo) Some studies of individual scientists address the contribution of individual judgement in the design and implementation of experiments and the interpretation their results.

Science can be characterised by organisational contexts

pp) Science is characterised by the ways people and resources are organised: it takes place in characteristic organisational contexts.

qq) Characteristic scientific organisational contexts include university faculties, departments, disciplines, and research teams comprising units within universities, companies, government instrumentalities and community-based groups.

rr) Scientific paradigms reflect some of these organisations.

ss) The rapid expansion and diversification of science in the twentieth century has generated both new scientific fields, and hence organisations, and new combinations of existing fields.

Science can be characterised by physical contexts

tt) Science is characterised by physical contexts such as locations and artefacts; locations include laboratories and field sites; artefacts include experimental apparatus and clothing.

uu) Traditional accounts tended to provide descriptions of artefacts and locations, and interpret their role as relatively incidental to the rational reconstruction of experimental activity.

vv) More recently, laboratory studies have focussed on the role of locations and artefacts in constituting scientific knowledge, arguing that the interaction of
people, apparatus and phenomena is more fundamental and complex than traditionally understood.

ww) In particular, laboratory studies have argued that laboratories can be interpreted usefully as the locus for complex sets of interactions between people, apparatus and phenomena that provide better characterisations of science than both traditional philosophical accounts of methodology and traditional sociological accounts of social interactions.

xx) Some post-positivist accounts argue that during the twentieth century, science became increasingly characterised by shifts in the interactions between technology (as in apparatus) and science, where the apparatus provides both the phenomena and the means of observing those phenomena.

II. Implications for a school science that is grounded in the metascientific literature

Given the conclusions in part I of the present section, above, there is a clear need to reconcile the traditionally internalist characterisation of science in the school curriculum with the far richer appeal to context in metascientific discussions. To do this we must examine the rationale for the internalist curriculum, which arises from several assumptions of particular interest to the present curriculum.

1) An assumption about the nature of science, that knowledge and certain processes characterise science, where knowledge comprises the framework of concepts and propositions currently accepted by the scientific community.

2) An assumption about the purpose of the science curriculum, that it should prepare futures scientists and technicians by giving them a thorough grounding in the accepted knowledge of science, that is, an internalist curriculum.

3) An assumption about potential scientists and technologists, that they are to be found among those school students with above average ability and interest in science; that is, with above average ability and interest in an internalist curriculum.
4) Another assumption about the purpose of the science curriculum, that it should prepare future citizens, who will include scientists and technologists, for life in an increasingly scientific and technological society.

5) An assumption about the nature of the learner, that students can develop a personal knowledge that is consistent with the accepted scientific concepts and propositions, and apply them in unfamiliar contexts, whether as scientists or as citizens.

The present thesis argues against each of these assumptions.

1) Arguments against traditional, narrow, characterisations of science

The present thesis presents a critique of the traditional view that science is characterised by knowledge and certain processes of reasoning and experiment. This critique is grounded robustly in the metascientific literature, and given in the semantic analysis of summary statements and the analyses in the six companion chapters and Appendix B. We have seen in the present chapter that characterisations of science only by its abstract logical and cognitive features is called internalism, and that extreme or exclusively internalist views are now widely thought by the scholarly communities that analyse science to inadequately characterise science. As the discussion on e/i debates showed, a strict internalism at best distorts the characterisation of science, and at worst provides a characterisation that cannot be sustained in the face of a very substantial academic literature. Likewise, extreme externalist characterisations, which seek to reconceptualise our understanding of the interactions between science and society by creating new concepts and terms, are contested in the literature partly because of this radical reconceptualisation, and partly because they fail to explain the cognitive criteria used by scientists to the satisfaction of the scientific community. In their extreme forms, internalism and externalism are unsuitable as a basis for a general school science curriculum. The failings of extreme internalism we have mentioned. Extreme externalism is also unlikely to be useful in a school curriculum because it does not characterise the cognitive character of science knowledge adequately, and in many cases no longer conceptualise sciences and society in the ways most people use those terms. Thus to
characterise science as equivalent to any other enterprise in society is to invoke a level of relativism that is not only contested strongly in the literature, but is at odds with the construction of a mainstream school curriculum. To suggest a school curriculum that relativises traditional subjects and entails a radically different notion of compartmentalising the curriculum is beyond the stated scope of the present thesis, which accepts the general structure of the curriculum and schools broadly as they are. However, both internalism and externalism are useful in that they offer different insights into the workings of science. A moderate externalism is considered to include insights from both perspectives, and is a suitable characterisation for school science (AAAS 1989, in Matthews 1994, p. 39).

Despite all this, the extensive e/i debates in the literature provide not only a range of perspectives on science, but some middle-ground positions in both HPS and STS that combine both internalist and externalist insights. As found in curriculum debates in many countries, including the debates accompanying the national curriculum framework project in Australia, e/i issues are central to arguments about what the nature of school science should be. The choice seems to be caricatured from both sides: one as a rigorous coverage of the intellectual tradition of science versus spurious social studies of science; the other as an empowering and socially-responsible education versus an intellectually sterile, technical approach to science.

Given the argument in the present chapter, school science should present a range of e/i characterisations and their insights, for two reasons. The first is simply to demonstrate the range of views of science. The second is that they represent, in various ways, fundamental characteristics of science that should be included if students are to develop a robust understanding of science. Science knowledge, for example, is a central concern in internalist characterisations and in all science curricula\(^2\). Equally, we have shown in the present chapter that this is inadequate to explain how science works, and that various external contextual factors play a part in constituting science. The main disagreement is how these factors work, and to what extent. Thus an historical perspective not only

\(^2\) Knowledge is addressed at length in Chapter 11 and Appendix B.6
provides an understanding of how current ideas came to be, but indicates their strengths by showing how they prevailed over competing ideas and their limitations by showing how they are accepted as tentative and depending on experimental tests. Even the milder interpretation of socio-cultural, human, organisational and physical contexts - that they influence science - is necessary to understand the strengths and limitations of science from the perspective of the citizen in a democracy. The stronger argument, that various contextual factors contribute essentially to scientific outcomes, should also be put. Thus the present thesis presents the following recommendations for the general school science curriculum.

a) School science should present a richer notion of scientific context than merely the intellectual, in such a way as to provide a coherent rather than anecdotal understanding.

b) There are plausible, even compelling, arguments that a broader notion of context than simply the cognitive actually constitute science, and that to fail to account for this is to fail to understand how science actually works.

c) Extreme internalism and externalism are strongly contested in the literature and unsuited as the basis for school science, except as indications of approach.

d) Plausible middle ground views, also found in the literature and well suited to the school curriculum, characterise scientific knowledge as appealing to empirical test and being socially constructed, i.e. as being subject to a range of contextual factors, including the cognitive, socio-cultural (in its broadest sense), and ontological.

e) School students need to understand something of the breadth of scope of scientific knowledge, to develop understandings about some concepts, and to understand that scientific knowledge derives its authority from its capacity for testing and revision; this understanding is best given by addressing a broader range of context than merely the cognitive.
2) \textit{Arguments against the assumption that internalist views are most adequate for preparing future scientists}

The second the assumption is that a purpose of the science curriculum is that it should provide a thorough grounding in the accepted knowledge of science, that is, an internalist curriculum, to prepare future scientists and technicians. This assumption has two parts: suitability of the internalist curriculum, and the preparation of aspiring scientists and technologists. An internalist school science is inadequate on several grounds. We have already shown that an exclusively, and even just a strongly, internalist view of science is flawed and inadequate. Therefore a school curriculum cannot base its rationale on a discredited view of the nature of science. While science is clearly characterised by knowledge, the companion chapter on knowledge and Appendix B.6 will show further that science knowledge is more complex than many traditional views address. There is a clear link in the literature between metascientific views and science education. The discussion of the notion of two cultures, earlier in the present chapter, mentioned its contribution to calls for 'liberalising' and 'contextualising' science education. Edge (1995, pp. 8-9) cites several reports in the UK that advocate such a shift, and indicates some of the debate that arose in response, debate which the present paper explicitly seeks to inform. He notes that the two cultures debate found expression not only in the growth of critical fields such as STS and SSK, but in the nature of science education, quoting Clive Morphet as an eloquent summation of this argument:

The justification for the inclusion of these non-vocational elements has ... always involved at its core the notion that courses in science and technology are essentially illiberal, being concerned with facts, objectivity, abstraction, specialisation, manipulation, etc., and that such a diet is unwholesome and should be 'balanced' or 'complemented' with a course or courses which expose students to more subjective ways of knowing and doing ... A cruder expression of the same sentiments will describe science and technology students (and, presumably, their teachers) as uncultured. (Morphet, unpublished conference paper, quoted in Edge 1988)

Even where all parties share an essentially positivist view of science, this claim could engender not only opposition but active hostility. Those of us who have experienced it know that this is one feature that has not changed over time! But it must be said that, rereading these pleas from the 1960s, I am struck again by how relevant their challenge still is ... Indeed, sharpened by subsequent debates about the need to recruit more women to science and technology, and their status within those professions, and by feminist critiques of science, the message has
been amplified. The positivist terms in which the ‘two cultures’ debate was set tended to separate science from the humane domain. Ironically, out of a (misguided) attempt to make science social and ‘civilised’ (as if it were part of neither society nor civilisation) has arisen a richer STS criticism. And yet the earlier rhetoric is constantly reemerging. (Edge 1995, pp. 9-10)

Thus characterisations of science in terms of the ‘two cultures’ have been debated, and continue to be debated, both in terms of (academic) metascientific argument and science education. This is self-evidently a concern of the present thesis.

If we consider for the moment only the needs of those students who may go on to a scientific career then there are several persuasive arguments for considering a wider context of science. First, the present thesis argues that a school Science that seeks to authentically represent science must show that broader notions of context help constitute science. This is part of the argument for increasing the rigour of school Science. The matter of rigour is addressed in the concluding chapter of this thesis because it draws on a robust, multidimensional characterisation of science, such as the present thesis proposes, and is not restricted mainly to context.

Secondly, the knowledge content of science is more intelligible if studied in historical, socio-cultural and personal contexts:

Solomon (1987) reviewed the scattered literature on a number of social influences that make the teaching of a rigidly insulated science, which has no contact with everyday contexts, nonsense for any group of students and a quite untenable option if the curriculum’s intentions are widespread learning (Fensham 1992, p. 803).

This is an argument from the perspective of improving learning practice, which is a derivative concern only of this paper, but nevertheless it holds. Thirdly, our future scientists should have a better understanding of science in the ‘real world’. This argument has two bases: increasing the rigour of the subject, and increasing the effectiveness of science as part of society. The matter of the effectiveness of science as part of society has been addressed in the discussion given earlier in the present chapter. For example, we have seen that much of scientific inquiry can no longer be characterised as arising from the intellectual curiosity of individual scientists, and instead arises from the interests of governments, industry and citizen groups. This also extends to determining questions of scientific authority: in only some cases is this determined as an internal matter for expert
scientific communities. In an increasing number of cases it is determined by government policies and funded by contracted projects set by industries, governments and citizen groups. In many of these cases the authority of claims to science knowledge is unclear because opposing groups use qualified scientists to support their own claims and dispute those of others; it is easier to characterise such disputes as being resolved by complex social negotiations involving competing cognitive claims rather than by straightforward appeals to cognitive arguments. A number of recent historical and other studies have shown that even a number of developments within the scientific community are better characterises as complex contests between authorities rather than simple tests of falsification or verification.

3) Arguments against the assumption that high achievement in an internalist curriculum selects our best future scientists

The third assumption is that potential scientists and technologists are to be found among those school students with above average ability and interest in science; that is, with above average ability and interest in an internalist curriculum. In part, this is reasonable and expected: it is natural that we should want bright and motivated students to choose to do further studies in science and technology. However, there is a circular argument if we claim that a bright and motivated student is one who excels at mastering decontextualised science knowledge, where such knowledge is used to define the bright and motivated student\(^3\). A way out of this circularity is to look for indicators of interest and ability beyond achievement in an internalist science curriculum, and there are sound reasons for doing this based on both educational and metascientific arguments. An example from metascience is the effect of gendered metaphors and other constructions in science on the involvement of women in science, as noted earlier in this chapter. In the science education literature there are many accounts of the deleterious effect of masculine imagery and decontextualised knowledge on the participation of particularly girls in school science; here, success or otherwise in school science is directly related to the

\(^3\) This is an example of the problem of the criterion in epistemology, where the criteria and extent of justified belief are confused; see Steup 1992, p. 378.
Chapter 6: Context

characterisation of context in school science, not on some notion of absolute ability. Likewise from metascience, Ravetz (1971) has characterised science partly by craft-like activities. In science education, the use of relatively open-ended inquiry projects is designed partly to encourage the learning of skills and concept development through activity, as in the learning of a craft. However, in the NSW science curriculum, the strong emphasis in the Science and Technology K-6 syllabus receives progressively less emphasis in the secondary curricula, and project work in the senior secondary years (11 and 12) tends to be restricted to the science courses regarded as non-academic; the most able and interested senior science students are encouraged to take distinct-discipline courses, particularly physics and chemistry.

4) **Arguments against the assumption that the traditional, internalist curriculum best prepares future citizens for life in a scientific society**

Fourth is the assumption that another purpose of the science curriculum is that it should prepare future citizens, who will include scientists and technologists, for life in an increasingly scientific and technological society. Clearly, such a curriculum goal appeals to a wider notion of scientific context than a narrow interpretation of cognitive context, as argued in the present chapter. However, it is weakened in two respects. On the one hand its presence in the NSW science curriculum diminishes as children proceed from primary to junior secondary to senior secondary levels. Thus, a broad scientific and technological context is clearly present at the K-6 level; at the junior secondary (7-10) level it is moderately argued but at the time of writing its future is unclear; at the senior secondary (11-12) level, it is largely absent in the science courses regarded as ‘academic’, and its substantial presence only in the ‘non-academic’ alternatives (the General Science and Science for Life syllabuses) reduces the status of broad notions of science context. On the other hand, although the goal of educating citizens lessens the requirement for a strongly internalist curriculum, curriculum flexibility is necessary to allow educational decisions to be made about movement of students between academic and general strands in the

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4 See the companion chapter on activity and Appendix B.5.
curriculum. Thus often there is pressure to ensure that sufficient knowledge of scientific concepts is covered in general strands should students wish to ‘step up’ to pre-university courses, which is interpreted commonly as changing the relative emphasis on the intellectual content versus the social utility of science. This is most evident at the junior secondary level, where the Science 7-10 syllabus allows schools considerable flexibility in principle for selecting the detail of content and presentation, but in practice schools are concerned to ensure that the more able students are well grounded in the knowledge that will prepare them for the senior science-discipline courses (particularly physics and chemistry), should they elect to do them. In this way the entry requirements into tertiary science-based courses influence senior science subject choices, which in turn apply pressure to retain an essentially internalist perspective on the junior secondary science curriculum at the school level.

To the extent that school science represents science, it should encourage students to appreciate that there are diverse views about science, including, here, scientific contexts: students should be aware that people construct and use different characterisations of science, and for different reasons. It is only by appreciating a broad notion of scientific contexts that various scientistic arguments in public life can be understood, and with it the ability to make informed contributions to public debates that draw on science. There are several implications for school science. Most obviously there is a need for school science to assist students to deconstruct public images of science, particularly stereotypic ones. There is also a need for students to develop some appreciation of the tension between ideals of science, such as goals of objectivity and rationality, and the actual practice of science. There is a need to ‘humanise’ science by considering more of the human contexts, such as individual personality, interest and motivation: we have noted that the science education literature shows that far too many students, notably girls, lose interest in science through their school science course. Patently, this is the exact reverse of the desired outcomes of a science education, both for an educated citizenry and future scientists and technologists. Science students need to understand that contemporary science is as it is because of historical antecedents, and, as with historical examples of
science, capable of revision. Thus an appreciation of science history engenders an understanding not just of how contemporary science came to be as it is, but also of the special sense in which scientific knowledge is regarded as both authoritative and tentative, and of why some ideas that were once regarded as plausible (even true) are now no longer thought to be so. Yet historical contexts are usually not addressed by much more than incidental or background biographical notes; that is, there is little planned attempt to develop a systematic understanding of science from its history. Likewise, a powerful technique for characterising western European science in the literature is to compare and contrast (western) science with natural philosophies in other cultures, yet in NSW at least this receives little planned attention except where individual schools choose to do so. That it may receive some attention in social studies classes would more likely serve to emphasise the internalist character of school science, and results in a piecemeal characterisation of science. There are some examples internationally where the scope of science curricula has been broadened to include traditions from other cultures, a direction that the present thesis can inform. While the science curriculum typically addresses the traditional disciplinary organisation of science, as physics, chemistry, biology and so forth, as found in universities, it should also address the considerable scientific activity in government agencies, industry and community-based groups such as consumer and environmental groups.

The physical contexts of school science bears a moderate resemblance to contemporary science: school laboratories are equipped with some artefacts that are recognisably scientific such as workbenches with water, gas and electricity outlets, and are stocked with glassware, balances and other artefacts that characterise scientific laboratories. However, some artefacts in school laboratories are no longer used in contemporary science, or largely so, such as cathode ray tubes, simple microscopes and even bunsen burners. Conversely, many artefacts used in contemporary science are absent from schools, such as complex optical microscopes, electron and ion microscopes, various electronic imaging and spectroscopic analysis machines, and sophisticated computer software. The reasons for this discrepancy include cost, physical and
conceptual simplicity suited to school students, and dated coverage in the curriculum. Thus, the cost of purchasing and maintaining sophisticated apparatus is frequently beyond the resources of universities, let alone schools, the more so when purchasing items of even moderate expense such as electronic balances involves foregoing the purchase of other useful artefacts. Of course, sophisticated equipment invariably requires extensive training in its correct and safe use, as provided in undergraduate and sometimes postgraduate science courses, and this is regarded traditionally as beyond the ability of most school students. Conversely, a justification for using simpler equipment is that they are simpler to use and to understand: for example the mechanisms themselves of beam balances, spring balances and simple optical microscopes help to demonstrate basic concepts whereas the electronic circuitry in electronic balances and electron or ion microscopes does not. The third reason, that the curriculum as formally embodied in printed documents and implemented by teachers whose science knowledge is dated, is challenged by the present thesis. To the extent that science is characterised by its physical contexts, school science needs to ensure it characterises not just historical science but its ongoing developments.

The present thesis does not advocate a radical shift of the school science curriculum from one essentially grounded in the western European science tradition into cross-cultural studies of comparative natural philosophies, although it allows for such a possibility should the curriculum developers of an education system choose to do so. (Hopefully, the present thesis would make such a choice, were it made, better informed.) Rather, it seeks to inform decisions about the broad subject called Science in Australian and similar school systems, that is, where school Science is based on the western European science tradition. As mentioned earlier, the focus of the present thesis on the western European scientific tradition arises from its concern to address adequately the tradition of science embodied in these science curricula, as a device for informing the deliberations of curriculum stakeholders. Once established, the proposed framework of categorisation can be applied to other traditions of science and for any curriculum.
5) Arguments against the assumption that students will modify their own belief system in the light of experience with a traditional internalist science curriculum.

Fifth is the assumption that the learner can develop a personal knowledge that is consistent with the accepted scientific concepts and propositions, and apply them in unfamiliar contexts, whether as scientists or as citizens. The complexities of research concerning learning science are largely beyond the scope of the present thesis, but some comments should be made. Briefly, the present thesis rejects the assumption that acontextual, propositional knowledge, as commonly given in science textbooks and embodied in science curriculum documents, can be learned as personal knowledge and applied in novel contexts, by the majority of school students.

This is the thrust taken by the report, *Science for All Americans* (AAAS 1989). It presents a number of conclusions and advocates a number of approaches, some of which match, and some of which conflict with *Science For All* approaches (Fensham 1992, pp. 800-801). The report advocates reversing the trend of adding more and more to school science curricula. (In preparation of the report, educational criteria of ‘utility, social responsibility, intrinsic value of knowledge, philosophical value and childhood enrichment’ were used to reduce some of the more extensive lists of topics proposed by panels). The report employs content that is very conceptual ‘and largely confined to the concepts science uses to describe the various scientific phenomena of importance’. Fensham is doubtful of the effectiveness of the argument for experiment and activity: ‘an experiential emphasis is recommended but underplayed as a goal’. *Science for All Americans* also recommends an historical perspective, although again Fensham queries its translation into school practice. This is advocated for two reasons: to gain appreciation for the way ideas are ‘products of their historical time and place’, and to gain appreciation for the ‘cultural salience of some of the great episodes of scientific endeavour’. Fensham is sceptical of the success of the implementation of the latter, given the tertiary socialisation of teachers. The report recommends that the contribution and potential of women and minority groups should be illustrated, but it should be made clear ‘to girls and minority
students that they are expected to study the same subjects, at the same level, as everyone else and to perform as well'.

**Context in NSW science syllabuses**

The NSW science curriculum, as an example of a mainstream science curriculum, indicates some ambivalence towards scientific context on the part of its curriculum developers and stakeholders. At the Primary level, the *Science and Technology K-6* syllabus makes a fairly consistent argument for learning science and technology in plausible contexts for primary children, rather than presenting decontextualised knowledge organised around traditional science disciplines. This may be regarded as a moderately externalist approach, although it is far more prescriptive about the knowledge to be covered than the process-oriented *Investigating Science K-6* policy (1980) it replaced. The change towards increasing specification of content reflected broader policy changes toward developing curricula that specified knowledge content more explicitly. An internal evaluation (NSW Department of Education, unpublished, 1989) of the 1980 policy by the then NSW Department of Education, in which the present author participated, showed a low rate (less than 10%) of implementation in schools, largely because teachers felt that policy provided little support in selecting, programming and teaching knowledge.

The junior secondary level is covered by a single syllabus, the *Science 7-10* syllabus (1985, amended 1989, and under redevelopment at the time of writing). This syllabus is aims-based, meaning that is provides a framework of concepts from which schools and teachers are to select knowledge content detail. A formal review of this syllabus was begun in 1996, but as of the end of 1997 the outcome of this review is not finalised. Certainly, a syllabus review Symposium held in May 1996 reflected a concern to address the knowledge of science disciplines, and much of the discussion at that symposium concerned whether or not traditional (internalist) science knowledge should be promoted more strongly or not in any syllabus revision (NSW Board of Studies, 1996).
At the senior secondary level, science studies are optional for students for the first time, and a small but increasing minority of students are electing to take no further science studies. At this level there were basically two types of courses available: discipline-based courses (*Physics, Chemistry, Biology and Geology*, of which students may elect one or two, and a multidisciplinary course); and interdisciplinary courses, *Science for Life* and *General Science*). At the time of writing, these interdisciplinary science subjects, among others, are being discontinued following the recommendations of The 1996 McGaw Report for the NSW Higher School Certificate. The discipline-based courses are strongly internalist; the interdisciplinary courses presented a moderately externalist view of knowledge, and led students to acquire knowledge through the study of issues and themes of social and personal relevance. In general, it is the discipline-based subjects that are regarded as the best pre-requisites for further science studies at tertiary level, and students intending further science or technological studies are encouraged to take these, particularly physics and chemistry. At the time of writing the statutory Board of Studies has recently undertaken a general review of the secondary curriculum and the prospects for secondary syllabuses, including science syllabuses, is for more discipline-based approaches. The situation is compounded further because in Australia there was an attempt in the early 1990s to provide national, common, curriculum profiles to reduce the variation between the curricula in each state. However, in NSW, the largest education system in Australia, the Eltis Report (1995) reviewed the curriculum and recommended that the national curriculum profiles should be taken into account but not over-ridden by the state curricula set by the Board of Studies; this recommendation was accepted by the government. The national Science Profile is, from the point of view of the present thesis, largely internalist: four of the six content strands correspond strongly with traditional science knowledge disciplines. However, it still has some critics who see it as downgrading the rigour of traditional science disciplines.

*Some specific recommendations corresponding to the summary of findings in part I above:*
Throughout the following, students should develop an appreciation of science context as part of developing a multidimensional characterisation.

*Science is characterised by context in a variety of ways*

**a-c)** Students should develop an appreciation that science is characterised by a variety of notions of context.

**d-h)** School Science should present insights from both internalist and externalist positions, and avoid extreme positions of either. For example:

- Students should develop an appreciation of the cognitive criteria by which scientific knowledge is formed and scrutinised.
- Students should develop an appreciation of how social, political, industrial, military and other contexts characterise science.

*Determining the context of the scientific and the non-scientific is described in the literature as boundary work*

**i-o)** Students should develop an appreciation of the ways in which different groups and individuals distinguish science from non-science, and the criteria and purposes used in doing this. For example:

- Students should develop an appreciation of and apply some of the central means by which scientists and metascientists characterise science, such as Popper's criterion of falsifiability, Kuhn's notions of paradigms, problem-solving and consensus views, and Merton's four social norms of science, namely *universalism, communism, disinterestedness* and *organised scepticism*.
- Students should appreciate that essentialist approaches to boundary work, like those of Popper, Kuhn and Merton, are flawed, although they are used as ideals to which science aims, and that constructivist approaches are also useful. For example:
• Students should analyse case studies of boundary work for strengths, weaknesses and purposes of attempts to distinguish science from non-science, using a multi-dimensional characterisation of science to do this.

• Students should develop an appreciation of both the insights of a moderate relativism, and the pitfalls of an absolute or strong relativism.

Science can be characterised by its intellectual context

p-s) Students should develop an appreciation of the intellectual or cognitive contexts of science, and their importance in characterisations of science. For example:

• Students should have opportunities to develop an appreciation of the available ideas, beliefs and concepts as the intellectual context within which scientists, and others, work and think, in particular the nature and scope of science knowledge (see chapter 11).

• Students should develop an appreciation of different notions of intellectual context: as science knowledge; as the paradigms within which communities of scientists do normal science; as communities of scholars; and as interdependent theories and auxiliary theories.

• Students should develop an appreciation that because the intellectual context is subject to testing and revision, it is authoritative while at the same time dynamic and tentative.

• School Science should foster in students a love of learning and applying knowledge.

Science can be characterised by its historical contexts

School science should provide students with opportunities to develop an appreciation of the historical contexts of science. For example:

• Students should develop an appreciation of the western European tradition of science, and that current science knowledge and practices derive largely from that tradition.
• Students should develop an appreciation of how some ideas have been enduring in science, while others have changed.
• Students should use historical case studies to show how various ideas were developed or rejected.
• School Science should not confine itself to a Whig history approach, and should include ideas that are not necessarily antecedent to present understandings, in order to understand better how ideas can rise and fall from favour.

Science can be characterised in various ways by socio-cultural contexts

z-gg) School science should provide students with opportunities to develop an appreciation of the socio-cultural contexts of science. For example:
• Students should develop an appreciation of the ways in which science is affected by, and affects, other subcultures within society, such as religious, economic, citizen, political and military interests.
• Students should develop an appreciation of the interactions between science, technology and society.
• Students should develop an appreciation of how phenomena are interpreted through a world view or Weltanschauungen, which may arise from particular scientific and broader cultural contexts, including non-masculine and non-European perspectives.
• Students should develop an appreciation of non-western European natural philosophies, and use a multi-dimensional characterisation of science to develop insights into the strengths and weaknesses of different traditions (including western European science), and the difficulties in making cross-cultural comparisons.
• School Science should avoid making simplistic characterisations for or against either western European science or other natural philosophies, and instead use multi-dimensional characterisations.
Science can be characterised by human contexts

hh-oo) School science should provide students with opportunities to develop an appreciation of the human contexts of science. For example:

- Students should develop an appreciation of the actual, and not just idealised, activities of scientists.
- Students should identify their own preconceptions of scientists, and develop an appreciation of widely used stereotypes and their implications.
- Students should have opportunities to learn about the roles of competition, ambition, incentive, motivation, interest, confidence, and the personality of past and present scientists, such as through biographies and visits to and by practising scientists.

Science is characterised by organisational contexts

pp-ss) School science should provide students with opportunities to develop an appreciation of the organisational contexts of science. For example:

- Students should develop an appreciation of the ways people and resources are characteristically organised in science, such as university faculties, departments, disciplines, and research teams comprising units within universities, companies, government instrumentalities and community-based groups.
- Students should develop an appreciation of the ways in which the organisational contexts of science are changing with changes in knowledge, changes in society and so forth.

Science is characterised by physical contexts

tt-xx) School science should provide students with opportunities to develop an appreciation of the physical contexts of science. For example:

- Students should develop an appreciation of the ways in which locations, such as laboratories and field sites, and artefacts, such as experimental apparatus and clothing, characterise science.
• Students should develop an appreciation of the ways in which people, apparatus and phenomena interact in the production of scientific knowledge.

• Students should develop an appreciation of the effects of scientific developments on technology, and of technological developments on science.

Conclusions on context

The very considerable body of constructivist science education literature shows that the prior understandings of learners, which the present thesis interprets also as prior beliefs, has powerful effects on what they construct as knowledge that are resistant to knowledge-transmission modes of teaching. This literature also shows that children do not transfer concepts well to novel situations, at least not without planned and effective intervention by teachers. The present thesis therefore argues that, whether we are considering science education for the preparation of scientists or for the scientific literacy of citizens, the science curriculum should specifically address the transfer of concepts to novel situations, and not simply assume that students will do this of their own accord. Thus, an internalist curriculum is further inadequate in this respect: familiarity alone with the acontextual propositions and concepts that comprise an internalist curriculum is not a good preparation for applying knowledge in novel contexts, a result we would expect from a science education, and if combined with traditional, transmission-based modes of teaching is an ineffective curriculum for acquiring science knowledge in the first place.
Chapter 7

BELIEF SYSTEM

A belief system, as in a systematic set of beliefs about the nature of reality and the proper orientation to this reality, is a necessary, but not sufficient, characteristic of science.

Introduction

This chapter comprises an argument that a belief system is a necessary, but not sufficient, characteristic or dimension of science. A belief system is defined generally, as a set of related beliefs, attitudes, values, assumptions, and criteria for decisions, that is often unstated or implicit:

A belief system is a set of related ideas (learned and shared), which has some permanence, and to which individuals and/or groups exhibit some commitment. (Borhek & Curtis 1975, p. 5)

This thesis takes the meanings of terms such as belief, attitude, value and assumption to be the non-technical meanings in general usage, as found in general dictionaries such as The Macquarie Dictionary (1985). Thus belief is taken to be an assent or agreement to, or conviction of, the truth of some proposition, but not with the certainty of knowledge, at least as it is commonly used. Attitude is interpreted as the adoption of a position or disposition toward something. Value is taken as ideals, customs and the like, towards which people have an emotional regard. Assumption is taken as that which is taken for granted, and priority to be a precedence in order. The companion chapter on knowledge and Appendix B.6 discuss more technical meanings of belief and knowledge, and the relationship between the two, as used by philosophers and others. A belief system is the notion that these beliefs, attitudes and so forth are interrelated; although interpreted generally, a particular model is discussed and adopted in this chapter.

This chapter will argue that a belief system is a necessary dimension of science in that the meanings of characterisation in the metascientific literature are incomplete without it, and that the meanings of the other proposed dimensions do not substitute for its omission.
It is not a sufficient dimension of science in that it does not completely characterise science. Where science is characterised by a belief system this thesis argues that it is usually characterised in combination with one or more other dimensions of science: knowledge, purpose, context, structure and activity. These other dimensions are used in explicating the belief system, and the belief system is used in explicating the other dimensions. A scientific belief system is not simply any set of beliefs, but a systematic set characterised by its association with particular knowledge, purposes, contexts, structures and activities.

Many popular characterisations of science do not mention belief system. This is partly because of the influence of the positivist Received View of science for much of the twentieth century, according to which science is neutral, free of values, and provides certain knowledge, not mere beliefs or opinions. Of course, this view itself represents a belief about the nature of science, and implies further beliefs about the nature of the cosmos. It is one of various views explored in this chapter. Belief systems tend to be inexplicit also partly because the very unstatedness of beliefs, assumptions and the like means that their use is implicit and unrecognised. Nonetheless, this chapter will show how elements of belief systems form part of characterisations in the metascientific literature.

The argument in this chapter is made in four parts:

1) evidence from the analysis of the summary statements;
2) evidence from argument in the metascientific literature;
3) the relationships between the dimension of belief system and the other dimensions;
4) conclusions for use in theorising about the school science curriculum.
1) Evidence from the analysis of the summary statements

The collection of classes (in Table A.8) and text units from the differentiae (in column 6 of Table A.9, headed *Foundational*) collectively indicate that science is characterised partly by a related set of (usually unstated) beliefs, attitudes, values, criteria and assumptions. The present thesis interprets this set as a belief system, as mentioned below in section 2.1 and discussed in Appendix B.2. As with the other dimensions, this category of characterisation was constructed from a semantic analysis of many metascientific sources. Thus it includes a wider range of viewpoints than do many individual accounts in the literature. The following examples from the summary statements are characterisations of science by belief system.

**Belief system**

Some summary statements refer explicitly to belief system, for example:

Belief systems ... are structures of norms which bear some relationship to each other and vary greatly in the degree to which they are systematic. What is systematic about belief systems is the interrelatedness of the various substantive beliefs. Some systems are more tightly interrelated than others.

At one end of the continuum are belief systems that consist of a few tightly linked general statements from which a fairly large number of specific propositions can be derived. Confronted by a new situation, the believer may refer to the general rule to determine the stance he should take. Science is an example of such a belief system. The principle of the experiment remains the same regardless of the differences in empirical problems to which it is applied ... the rules of scientific method, being systematic, may be applied to all kinds of data without regard to their location. Thus, a high degree of system is in one sense an aid to diffusion of belief ... (Borhek & Curtis, in summary statement 75)

Some statements imply a belief system:

[The term science is used sometimes to refer to] a myth, that is, a systematic set of beliefs about the nature of reality, about the appropriate way to relate to reality and about the "discipline of the self" ... necessary to achieve an appropriate relationship to reality. (Kenny, in summary statement 14)

**Myth**

Kenny (above) interprets *myth* not as a fantastic or unreal story, as the term is sometimes used, but as a widely held set of beliefs that is meaningful for a group in society. Bernal uses *mythology* in the same way, adding that it is rationalised, meaning that a science belief system follows certain rules and criteria:
Science, in one aspect, is ordered technique; in another, it is rationalised mythology. (Bernal, in summary statement 23)

**Thought**

In summary statement 10, Einstein also uses the notion of thought - a *logically uniform system of thought*. This might ordinarily be thought to mean system of knowledge, but this is just as meaningful if interpreted as a system of beliefs:

Science is the attempt to make the chaotic diversity of our sense experience correspond to a logically uniform system of thought. (Einstein, in summary statement 10)

That is, the chaotic diversity of our sense experience can be made meaningful when interpreted using our belief system. The dimension of *system* is taken up in the companion chapter on structure and Appendix B.4.

**World view**

The same applies to the notion of a *world picture* or *world view*, which can be interpreted as a set of beliefs about the world that is meaningful because partly because it is cohesive:

Science is a world picture. It is not a technique; it is not a form of power; it is not even simply an accumulation of knowledge. But it is a highly integrated form of knowledge which makes a world view. (Bronowski, in summary statement 16)

[S]cience is not an independent, value-free dissociated activity ... [T]here is no distinction between scientific strategies and human strategies in guiding ... how to look at the world. Science is a world view based on the notion that we can plan by understanding ... [S]cience is distinguished from magical views by the fact that it refuses to acknowledge a division between two kinds of logic. There is only one kind of logic; it works the same way in all forms of conduct and it is not carried out by any kind of formula but by an active view of how you apply the logic of long-term planning strategies to the conduct of the whole of your life. Finally, and most crucially, science is distinguished from earlier forms of trying to achieve a unitary view of the world by the fact that there is only one form of truth in it. There is no distinction between man [sic] and nature, there is no distinction between the logic of magic and other logics, and there is no distinction between means and ends. (Bronowski, in summary statement 73)

**Elements of belief systems**

Some statements refer to elements of a belief system, such as beliefs, attitudes, criteria and rules:
Science may be taken ... as one of the most powerful influences moulding beliefs and attitudes to the universe and man [sic]. (Bernal, in summary statement 24; emphasis added)

A common interpretation of belief and science is something like, In the past people believed things but now we (say we) know. As we will examine in this chapter and the companion chapter on knowledge and Appendix B.6, this connection between knowledge and belief commonly centres on the extra certainty we have of knowledge, such as justified true belief or consensus within a scientific community. Since current, post-positivist metascientific thinking acknowledges the capacity of science knowledge for revision, there has been a re-examination of the role of belief in science. An example is Beer:

I. A. Richards attempted a less metaphysical answer to the ... linguistic problem of what styles of belief are demanded by literary and scientific texts from the reader. He contrasts, without preference, the ‘statements’ of science and the ‘pseudo-statements’ of literature ... Statement (which we might now call propositional discourse) demands belief; pseudo-statement does not. (Beer, in summary statement 100, emphases added)

Attitudes, motivations and belief

[There has arisen] a standard view [of science], largely shared by reflective scientists, technical philosophers, and the educated public alike, and laying great emphasis upon the objective features of scientific thought ... The current attacks thus challenge not only a firm set of habitual attitudes, but ... the underlying moral motivation of these philosophies, their upholding of the ideal of responsibility in the sphere of belief as against wilfulness, authoritarianism, and inertia. (Scheffler, in summary statement 25; emphases added)

While Scheffler explicitly mentions belief and attitudes, characteristics like objective features and moral motivation are also elements of a belief system, in that they represent beliefs about criteria about how science should be done, and what is scientific or not.

Curiosity, desire and emotions

Similarly, while Baker does not explicitly use the term attitudes, he characterises science by several attitudes, such as curiosity, desire and pleasure:

Although curiosity and the desire to generalise are the mainsprings of the scientific mind, yet clearly they cannot alone create a scientist: originality and intelligence and perseverance are necessities, and the finding of pleasure in the use of the hands in delicate manipulations is very nearly necessary. (Baker, in summary statement 64)
Objectivity and criteria

Scheffler, again, characterises objectivity, which is a set of ideals and criteria for making judgements about what is scientific, as leading to an ontological vision, meaning a cohesive set of beliefs about the nature of reality:

Objectivity [culminates in an] ontological vision ... (Scheffler, in summary statement 26)

Grünfeld characterises science by a set of rules for science (logic and rationality), that are elements of the belief system, by criteria and attitudes (commitment) that are also elements of the belief system:

What science gives us is criteria of judgement ... and a commitment to logic and rationality. (Grünfeld, in summary statement 29)

Harré likewise characterises science by a set of rules (ideals of scientific reasoning) that apply to an attitude (confidence) and, by implication, are criteria for judgment:

Actual science [entails] ideals of scientific reasoning ... by which the effect of new evidence on our confidence in the truth of laws is assessed. (Harré, in summary statement 39)

Similarly, Rapoport refers to rules (principles) that entail values and criteria (ethical, objective) and attitudes (conviction):

These ... are the ethical principles inherent in scientific practice: the conviction that there exists objective truth; that there exist rules of evidence for discovering it; that, on the basis of this objective truth, unanimity is possible and desirable; and that unanimity must be achieved by independent arrivals at convictions - that is, by examination of evidence, not through coercion, personal argument or appeal to authority ... (Rapoport, in summary statement 53)

Values

Other elements of a belief system are values:

Science is a deceptively inclusive word which ... is commonly used to denote ... a set of cultural values and mores governing the activities termed scientific ... (Merton, in summary statement 30; emphases added)

Science is a problem-solving sub-culture whose main value is truth. (Boulding, in summary statement 59; emphasis added)

[T]he value posture hospitable to scientific endeavour is rationalistic in the choice of alternatives, relativistic in judgement and expectation, and anticipatory of change ... [The scientist] can bring differing value judgements into play ... The values of science, to become effective, must be supported by more general societal values ... (Silvert, in summary statement 31)
Silvert characterises values as interacting with rules for judgments (rationalistic and relativistic) and attitudes (anticipatory).

Beliefs about the cosmos, or Nature, or the material world

Boas refers to what the present thesis interprets as belief system (a conception of a material world) in terms of rules, but which we might interpret as assumptions or beliefs:

[Philosophy] has taken over from physics a conception of a permanent and indestructible material world and inferred religious conclusions from the existence of that world. It has given to science certain rules, such as, "Nothing is made from nothing"; "Nature always follows the simplest course"; "Nature does nothing in vain"; and these and similar rules have determined the kind of scientific conclusions that would be acceptable ... Each of them is based on some metaphysical dogma, some dogma that is usually unexamined. It is unexamined because it had been part and parcel of collective thinking and seems self-evident. (Boas, in summary statement 63)

These rules can be interpreted as criteria for judgement which, as will be argued presently, can be interpreted as elements of a belief system. Some statements refer to beliefs about the cosmos, and about how we can have knowledge of it:

By natural science we mean then a specific vision ... at once of knowledge and of the object of that knowledge, at once of natural science and of nature. We may trace the characteristically Western tradition of rational science and philosophy to the commitment of the Greeks ... to the decision of questions by argument and evidence, as distinct from custom, edict, revelation, authority or whatever else ... It was the Greek style of rationality to make this explicit by analysis of the reasoning involved, in the manner of Socrates. The Greeks developed thereby the conceptions of a problem as distinct from a doctrine. At the same time by deciding that, among the many possible worlds as envisaged in other cultures, the one existing world was a world of exclusively self-consistent and discoverable rational causality, they committed their scientific successors exclusively to this effective direction of thinking, and closed to them visions of things still open elsewhere. They introduced in this way the conception of nature, comprising a rational scientific system, in which formal reasoning matched natural causation, so that natural events and reasoned conclusions must equally follow exactly from true principles. Hence the two fundamental conceptions from which the characteristic style of all Western rational thinking has followed: causal demonstration and formal proof. (Crombie, in summary statement 61)

Some refer, either explicitly or implicitly, to the content of scientific belief as concerning the nature of reality. The literature refers to these as ontological beliefs, sometimes as metaphysical beliefs, that is, beliefs about the ultimate nature of being:

Science ... must necessarily have a philosophy [because its] disagreements are philosophical conflicts - conflicts, among other things, in regard to ultimate kinds of explanatory ideas ... (Gale, in summary statement 33, emphasis in original)

[Science is or involves setting] knowledge within a more comprehensive metaphysics. (Harré, in summary statement 38)
The sciences are regional ontologies and ontology is general science. After all, every substantive scientific problem is a subproblem of the problem of ontology, to wit, What is the world like? (Bunge, in summary statement 45)

As a result of the evolution of scientific thought, there has emerged a broad and coherent picture of the universe and of life in it... I will argue that this process of unification has not been restricted to the integration of beliefs about the world, but that there has also been a progressive tendency toward unification of those beliefs with the methods employed to attain well-grounded beliefs. That is, I will argue, the methods we consider appropriate for arriving at well-grounded beliefs about the world have come more and more to be shaped by those very beliefs, and have evolved with the evolution of knowledge. (Shapere, in summary statement 105)

Scientific theories are ways of looking at the world; and their adoption affects our general beliefs and expectations, and thereby also our experiences and our conceptions of reality. We may even say that what is regarded as ‘nature’ at a particular time is our own product in the sense that all the features ascribed to it have first been invented by us and then used for bringing order into our surroundings. (Feyerabend, in summary statement 113)

The final examples are taken from the remaining references in just the first twenty summary statements, to show further the wide, if usually implicit, reference to belief system:

- commitment to the testing of proposed explanations (5)
- belief in the ignorance of experts [interpreted as scepticism of the dependence on authority for knowledge claims, or recognition of the limitations of science] (6)
- commitment to accuracy in observation and merciless treatment of fallacy in logic (17)
- a naturalistic metaphysics and an empirical epistemology (20)
- to predict and control phenomena revealed by the metaphysics and epistemology (20)

Two comments should be made about these extracts. Firstly, not all these extracts agree with one another. This result supports an important contention of this thesis, which is to argue that characterisations of science appeal, first, to a range of beliefs, attitudes, values, assumptions and priorities, and second, that different accounts make these appeals in different ways, not just one way.

Secondly, while some statements explicitly refer to belief systems or elements of them, such as beliefs, attitudes and values, considerably more statements use terms that entail belief systems. For example, some terms label categories of beliefs, such as
metaphysics, ontology and epistemology, in philosophy: they represent beliefs about the cosmos and our knowledge of it. These terms are discussed in Appendix B.2. Some statements imply or entail beliefs, values or attitudes, and some statements do not discuss them singly or discretely. Statements using commitment, conviction, ideal, recognition and scepticism infer some unspecified blend of belief, assumption, attitude, and so forth. This seems to indicate that some authors consider these terms collectively. That is, collectively the terms attitude, belief, value, assumption and similar are used describe a cognitive state to partly characterise science. This collective use of terms and lack of individual specificity reflects the unstated nature of the cognitive state, and their inter-relatedness and collective meaning. To identify and delineate a particular belief that underpins an assumption or value requires a deliberate analysis of the sort attempted here. Only in this way can the unstated and assumed be made explicit. It is acknowledged here by describing the cognitive state indicated by the collective set of terms as a belief system.
2) Evidence from argument in the metascientific literature

Debates in the metascientific literature characterise science variously by belief system, which again supports a broad interpretation of science. Appendix B.2 indicates aspects of belief system as it used in characterising science, as summarised here. This list addresses some recurring themes, and is not definitive; it is intended as an indication of scope.

B.2.1 The notion of a belief system

Science is also characterised by an interrelated set of beliefs, values and assumptions, or by one element from such a set, that is, 'an interrelated cognitive system' (Rokeach 1972, p. ix). The present thesis adopts a model of belief systems proposed by Borhek and Curtis (1975) as a suitable account. In this model, belief systems comprise a number of elements, namely values, criteria of validity, logic (that includes language), a perspective or cognitive map, substantive beliefs (the content of the belief system), prescriptions and proscriptions (that include norms for behaviour), and beliefs 'concerning means to attain valued goals' (Borhek and Curtis 1975, p. 13, or technology beliefs.

Applying the concept of belief system in the present thesis

Several questions arise from this discussion of belief systems. What is the application of a model such Borhek and Curtis' to the claim of this thesis that belief systems partly characterise science? In particular, what is the relationship of the elements of belief systems to the proposed characteristics of science? What is to be made of the observation that elements of belief systems appear to apply to the other five proposed dimensions: context, purpose, structure, knowledge and activity? If this is so, how can a separate dimension based on belief systems be justified? Whether or not a separate category of belief systems is established, what is the role of the elements of belief systems in the other five dimensions? The answers to these questions, which comprise the following few pages, will establish a basis for the claim that a belief system is an identifiable dimension of science. The argument for the claim will comprise the remainder of this chapter.
To begin with, Borhek and Curtis's analysis is a plausible and useful argument that science is an example of a belief system. Their argument is made quite properly as part of an explication of belief systems and society; it is not extended to argue that science is completely and exclusively a belief system. The present thesis argues that while science might be characterised by a belief system, it cannot be characterised as a belief system, i.e. thought of alternatively as a belief system. For example, consideration of the context of science draws attention to artefacts of science - scientific disciplines as organisations, institutions, infrastructures, and equipment. These things exist materially. As discussed in the companion chapter on context and Appendix B.1, it makes sense to claim that science is characterised partly by the buildings, laboratories, faculties, departments and equipment that contribute to its context. They are more than just beliefs, although belief systems play a strong role in their design, construction and use.

The relationship of belief system to the other dimensions in the present thesis

The central issue at this point is the relationship of belief system to the other proposed categories or dimensions: is belief system restricted to one dimension of characterisation? On the one hand, claims about context, purpose, structure, knowledge and activity each entail some sort of belief: one option is, therefore, to address the elements of belief systems only as they apply in the other five companion chapters. In this sense each summary statement entails a belief or beliefs to which some appeal could be made to justify the statement: any definition of science entails a belief that the statement is so, that the statement is true and can be justified. Each entails beliefs, such as what is regarded as 'legitimate' scientific study. By extrapolation of this argument, beliefs are entailed in the justification and formulation of the other five dimensions. There is a sense that just about anything to do with science will entail some sort of belief, and if this is so, it begs the question as to how there could be a separate chapter concerned with a belief system.

Thus one option is to address belief system in each of those five chapters, and not as a separate chapter, because beliefs are associated with context, purpose, activity, structure and knowledge. The discussion of each dimension would comprise descriptions of what it entails, including the underlying beliefs, attitudes, and so forth. In this approach, the
criterion for establishing each dimension is the *subject of the belief*. For example, the chapter on activities would include not only a description of the processes that characterise science, but also the beliefs, values and assumptions entailed by, or which underpin, those processes. Where a proposition represents a belief about one of the other five dimensions it is included there. This option is rejected because there are elements of belief system that do not uniquely apply to any of the other dimensions, such as ontological and epistemological beliefs - beliefs about the nature of being and knowledge. Moreover, the approach does not make the concept of the belief system explicit.

Another option is to address belief system wholly or partly in a separate, dedicated chapter. This approach would accommodate the beliefs (and attitudes, values and assumptions) that do not apply uniquely to any of the other five dimensions. In particular, there are beliefs about the nature of the cosmos - the concern of science - and about how we can claim to have knowledge of this cosmos. These are ontological and epistemological beliefs, which, in Borhek and Curtis’s account, would largely be included as beliefs about perspective.

The present chapter is organised according to the second option. It addresses any proposition that constitutes a belief, attitude, or similar, of any sort; the role of belief systems in determining other dimensions of science will be mentioned also from time to time elsewhere in showing the interrelatedness of the six dimensions. The present thesis interprets belief system simply as a category of meaning in characterisations of science that the present thesis identifies along with five other dimensions of characterisation. The function of the present chapter, therefore, is to make clear how metascientific argument characterises science by belief system. This is the same rationale that applies to each of the six companion chapters: belief system one dimension of characterisation of science in its own right, and should be presented as a whole in one chapter.

*Implications of adopting particular beliefs*

On Borhek and Curtis’s account, the values, criteria of validity, language or logic and perspective of a belief system form a logically prior set. It is this set which is likely to be unstated and assumed, comprising the elements likely to be of least interest to scientists in
their day-by-day work. This prior set, together with prescriptions and proscriptions, appear to apply to the substantive and technology (enabling) beliefs that comprise and underpin the substantive beliefs in purpose, context, structure, processes and knowledge. Substantive beliefs by definition comprise much of the character of knowledge as a characteristic, and technological beliefs would apply substantially to the chapter on activity as a characteristic. Importantly, Borhek and Curtis’ nomination of technology beliefs as ‘often the meeting ground for fundamentally different belief systems’ (p.14) recognises that in the actual practice of science beliefs are formed and changed in a complex fashion that strictly intellectual analyses by ‘purists’ cannot explain. Prescriptions and proscriptions would appear to apply across the board.

Adoption of, or commitment to, particular underlying beliefs, attitudes, values, etc., has two related effects. It entails a particular belief system while denying others, and it entails certain alternatives in the other dimensions while denying others. Conversely, evidence of this particular purpose or that particular set of processes implies a particular underlying belief system, and denies others. We have seen that many of the summary statements refer to fundamental beliefs about the nature of reality, about how science can claim to increase our understanding of this reality and about how we can claim to have such knowledge. These do not relate uniquely to any of structure, purpose, concepts, processes or context. They will entail, or logically compel, values and attitudes about the sorts of behaviours and approaches that are necessary to carry out science successfully. They will entail prerogatives adopted in making scientific decisions. Therefore the claim to be made in the remainder of this chapter is that science involves not only beliefs about purpose, context, concepts, processes and structure (and which are found as part of these dimensions), but other elements of a system of beliefs, particularly concerned with the nature of the cosmos (ontological beliefs) and how we can have knowledge of that cosmos (epistemological beliefs).
A belief system provides the basis for choosing, prioritising, orienting, deciding what counts.

Given the foregoing discussion, some elements of belief system identified in the summary statements will be found in all six proposed dimensions of science. In the most general sense they indicate the beliefs and attitudes claimed to be held when involved in scientific activity - when thinking or acting to some scientific end. They are foundational, assumed, taken for granted. They provide criteria for judging what is important, valuable and worthwhile. They may be considered to include the set of priorities assumed when making fundamental decisions in science: the basis for choosing methods of investigation, what to accept, what to reject, what to look for, how to describe, what is worthwhile pursuing, what is not worthwhile pursuing, what is significant or is not, what is scientific or is not, what counts as evidence or does not count as evidence.

The present thesis therefore addresses belief system in a general sense to mean beliefs about what is to count in science, about what science is capable of, about what is within the proper domain of science, and the proper activity of people doing science. In a more particular sense, these beliefs include those about the nature of reality - the nature of the ordered universe or cosmos - and the orientation to this cosmos that will yield scientific understandings of it. By their very nature they are most often not even noticed by the individual. In a society in which scientific ideas are very much a part of the general pool of ideas of that society, the individual may not have considered even the very existence of assumptions, values and beliefs upon which those ideas depend. These beliefs will yield a view of what science is capable of, which would therefore guide the activities, thinking and decision-making of those who are involved in science. A belief about the capability of science also implies a view of what constitutes a fair appraisal or criticism of science and a view of what is a reasonable use of scientific knowledge/expertise in domains beyond science itself; this is more than a view of the limits of science.
Because beliefs are often implicit in thinking, they may only become evident when comparing systems of thought

Beliefs about the nature of the cosmos and how we have knowledge of it are embedded in everyday thinking, and therefore may not be readily apparent. It is difficult to appreciate the extent to which basic beliefs about the world underpin so much of the thinking in a culture, particularly one's own. The basic beliefs of Western European cultures about the cosmos are difficult to identify readily because they underpin so much of the conceptual framework of Western European science, and scientific thinking is widely promulgated in Western cultures. The philosopher Rom Harré made this clear by pointing to the assumptions or beliefs in watching something as commonplace as a horse-race:

There has to be a relatively permanent material frame of reference constituted by the course. There are moving material objects, the horses, which must continue to exist from the start of the race to the finish. Just think of the assumptions involved in believing that the horse which has just gone out of sight behind a large person who is blocking the view of the course is the same horse that is still leading after the horses emerge into view again. What would you say to a bookmaker who persisted in doubting that the horse which finished first was the one upon which one had bet at the start of the race because it had not been under continuous observation all the time? What would you say to a physicist who insisted that electrons existed only at such times as they were interacting with instruments? (Harré 1985, p.20)

The example of the horse race serves to show that there are beliefs and attitudes which pervade our thinking and are usually unnoticed. These are beliefs and attitudes about the cosmos and about how we claim to know about it. They may only become evident through comparison and analysis of the beliefs held in different cultures and different schools of scholarly theorising. As will be shown shortly, different philosophical accounts of phenomena such as Harré's horse race entail different basic beliefs, and as indicated above, such beliefs are the subject of theorising within the philosophy of science, especially metaphysics and epistemology, but also in the sociology of science and other traditions.

Accounts of these beliefs are made in metaphysics, epistemology, logic, sociology, history, linguistics and psychology

Probably the most fundamental beliefs are those concerning what science is claimed to produce knowledge about - the nature of the cosmos - and beliefs concerning how we
claim to have and justify this knowledge. They are the subject of much of philosophy: beliefs about the ultimate nature of the cosmos constitute the field of metaphysics; beliefs about what is to count as real rather than spurious knowledge are found in theories of epistemology; and beliefs about what is correct reasoning comprise the domain of logic. Metaphysics, epistemology and logic are interrelated, and comprise fundamental branches of the philosophy of science.

Rather unhelpfully, the term metaphysics is defined and used variously. Bhaskar (1983g) has noted a general meaning of metaphysics as a general world-view or philosophy, and a narrower interpretation as the nature of and relationship between theories of being, or ontology, and of knowledge, or epistemology. Harré (1985, p. 30) has characterised metaphysics as 'the study of the most general concepts used in science and ordinary life, through the study of the internal structure of the language used in different fields', and 'the study of the most general categories within which we think' (p. 100). Examples of such categories include space, time, thing and cause. Because there is more than one category, and more than one concept within each category, metaphysical systems of concepts have been proposed; these are cosmologies. A metaphysical system or cosmology serves to provide 'an adequate and a self-consistent system of concepts with which to understand the world as revealed in the results of experiments' (Harré 1985, p. 13).

Working definition of a belief system used in this thesis

In summation, the present thesis interprets the collection of terms, found in the summary statements and meaning beliefs, attitudes, values and the like, to mean belief system. For our purposes, then, a belief system is a set of interrelated beliefs, attitudes, values, criteria for judgements, and rules for how these beliefs are expressed in logic, language and behaviour, that are reasonably enduring and held by an individual or group. This is broadly based on the model of Borhek and Curtis (1975), although neither their nor any other one particular model is necessary to postulate here the usefulness of belief system as a dimension of characterisation.
B.2.2 Some current metascientific positions

The differences between various metascientific views - interpretations of science - rest partly on their different accounts of belief systems in science, whether implicit or explicit. These are summarised in Table B.2.1.

B.2.3 The role of belief system in characterising a western European scientific tradition

The notion of a Western European scientific tradition can be characterised partly by the historical changes in belief systems. Central are beliefs about the nature of the cosmos and of how to develop reliable knowledge of it.

B.2.4 Causality

Notions of cause and effect are central to science, and a scientific world view is commonly characterised as having beliefs of cause and effect that are distinct from other world views or belief systems (see, for example, Johnston 1986). Scientific beliefs about cause contribute to beliefs about Nature, God and magic, among other things; these are mentioned below and are also taken up in Appendix B.2.

B.2.5 Attitudes to Nature

Beliefs about the material world, or cosmos, are characterised commonly as beliefs about Nature. Central to the successes of the western European scientific tradition is that the cosmos is uniform and predictable, and therefore knowable; other influential beliefs have been that Nature behaves like a mechanism (and therefore can be understood as one) and that Nature behaves like an organism, a belief that is enjoying something of a revival in some circles. Beliefs such as these engender attitudes such as curiosity, whereas beliefs that Nature is capricious or wilful, as held in some other cultures, have engendered attitudes such as awe and fear that did not lead to inquiries of Nature.

B.2.6 Nature and magic

Science is sometimes characterised by its contrast with magic. However, like scientific belief systems, magical belief systems are characterised by beliefs about, and attitudes towards, Nature and how it works; the two can often be difficult to distinguish
unequivocally. Views that magic is pre-science or failed applied science are difficult to support historically. However, versions of magical beliefs in which Nature is ensouled, and beliefs in sympathies and antipathies, do differ from contemporary scientific beliefs. Also, Bronowski (1978) has argued that science, unlike magic, relies on a single logic of how the world works: that in science there is no ‘other world’ that works according to a different logic to everyday life.

B.2.7 Nature and God

The relation of God to Nature, and hence also the relation of God to science, has long been debated and continues to be so down to the present. It is highly significant that these conflicts are characterised less by particular knowledge claims or activities, the traditional categories of characterisation, than by fundamental concerns with belief systems.

B.2.8 Nature and mathematics

Science is characterised commonly as mathematical, and of particular interest here that the role of mathematics in science is predicated on a belief that the cosmos can be represented mathematically.

B.2.9 Metaphysical beliefs

Science is also characterised by beliefs about the ultimate nature of being, or ontological beliefs. This has included a belief that the material world ultimately comprises interacting particles, and more recently has included once again a belief in physics and metaphysics that Nature ultimately comprises fields rather than entities or things.

B.2.10 Experimentation

Science is also commonly characterised by a belief that experimentation is an appropriate way to gain knowledge of the material world. This entails a belief that Nature can be manipulated into independently variable factors in such a way as to show how these factors behave in their non-manipulated, that is non-experimental, state (Bhaskar 1983c, p. 136).
B.2.11 Models and metaphors

Science is characterised often by models and metaphors that are used to represent elements of belief systems: fundamental beliefs, assumptions, values and attitudes. An example is the mechanistic model, which represents a complex and often implicit set of factors elegantly with a single model or metaphor.

B.2.12 Other belief systems

The western European tradition of science is also characterised sometimes by contrasting its fundamental assumptions, attitudes and beliefs with those of other cultures, both historical and extant. Examples covered in Appendix B.2.12 include animistic beliefs, different beliefs about time, predestination, reincarnation and cause and effect, and non-inquisitive attitudes arising from beliefs that Nature is capricious and unknowable.
Belief system as a necessary characteristic of science

The argument to this point of the chapter establishes belief system as a (semantic) category of characterisation in the literature. It does this firstly by arguing that a number of terms in the summary statements, such as belief system, beliefs, attitudes, assumptions, values, criteria of judgement and priorities, can be meaningfully interpreted as belief systems or elements of belief systems. Secondly, it argues that science is characterised in the literature by a range of views about the nature of belief systems. Central among these are different beliefs about the nature of the cosmos (ontological beliefs) and of our knowledge of it (epistemological beliefs), but they also include different assumptions that scientists make, values they hold, and so forth. Various theoretical interpretations of science can be characterised partly by how they characterise science by belief systems: central to empiricism is the belief that knowledge of the cosmos is perceptual, to constructivism that knowledge arises from mental states, and from realism that the subject of scientific study is an external reality.

Belief system is a necessary characteristic not because of any particular arguments addressed in the present chapter, but because the variety of accounts reviewed here characterise science partly by appealing to belief systems and would fail without doing so. That is, science necessarily concerns belief systems: systems of related beliefs, attitudes, values, assumptions and so forth. The fact that characterisations of science do not always explicitly mention belief system arises because these elements of belief systems are typically implicit, or unspoken, not because belief systems are unnecessary. To adopt a particular belief system is to adopt criteria for judging what is to be scientific or not, what activities to use, what criteria to apply and what assumptions to make. Characterisations of science fail if we remove these references to belief systems.

To understand the nature of science, one must at least be aware that the literature characterises science by belief system, construes belief systems in various ways, and, ideally, understand at least some of the insights of the major positions. As with the other dimensions of characterisation, to recognise only a single position from the literature is to
fail to understand that there may be plausible alternatives, and hence possible alternative insights, and especially to be unable to defend a particular view from the attack of other views. One cannot appreciate the strength of a claim to be scientific without appreciating the strength of alternative arguments. It follows that to understand science, one must: first, understand the central role of belief system in characterising science; second, appreciate the diversity of accounts of belief systems; and third, appreciate the insights of some alternative characterisations.
3) The relationships between the dimension of belief system and the other dimensions

Following the discussion in Appendix B.2.1, elements of belief systems apply fundamentally to each of the other dimensions: knowledge, activity, purpose, structure and context. We will illustrate this interrelationship using two examples. One is some historical beliefs about experimentation as beliefs central to an enduring, characteristic activity of science. The other is the Gaia hypothesis as an example of a belief about Nature that derives some of its meaning only by considering a wide and recent context of science.

Some historical beliefs that underpinned and justified experiment

Two influential writings on scientific activity in the history of science have been those of Isaac Newton and John Stuart Mill, mentioned earlier. Both gave some principles or rules for scientific activity, but although these are well known in histories of science, it is rarely recognised that they are not recipes or descriptions of activities, but instead are beliefs, assumptions and criteria about gaining knowledge of the material world. That is, they are elements of belief systems. Thus Newton's four Rules of Reasoning in Philosophy, in the 1687 third edition of the Principia, comprise criteria that arise clearly from beliefs about the cosmos:

1. We are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances.
2. Therefore to the same natural effects we must, as far as possible, assign the same causes.
3. The qualities of bodies, which admit neither the intensification nor remission of degrees and which are found to belong to all bodies within the reach of our experiments, are to be esteemed the universal qualities of all bodies whatsoever.
4. In experimental philosophy we are to look upon propositions inferred by general induction from phenomena as accurately or very nearly true, notwithstanding any contrary hypotheses that may be imagined, till such time as other phenomena occur, by which they may either be made more accurate, or liable to exceptions. (Newton 1713/1934, pp. 398-400).

It is interesting to note a post-modern flavour to Newton's fourth point particularly, that knowledge is revisable and relative. This is not always made explicit in positivist characterisations of science.
Similarly, Mill’s Canons of induction, well known in histories of science, are not so much descriptions of activities but principles for conducting inductive inquiry. That is, they also are elements of a belief system:

[Mill’s Canons] concern the isolation of those circumstances which are related to the phenomena studied by causal laws. They comprise

1. The Method of Agreement: if two instances of a phenomenon share only one circumstance, it is either their cause, or effect.
2. The Method of Difference: if an instance in which a phenomenon occurs and one in which it does not differ in only one circumstance, it is the cause, or effect, or an indispensable part of the cause, of the phenomenon.
3. The Joint Method of Agreement and Difference: combining the previous two, putting together knowledge of what is common to all cases of the phenomenon and what alone differs when it is absent.
4. The Method of Residues: subtract from a phenomenon what is known already to be the effect of certain antecedents, and the residue is effect of the remaining antecedents.
5. The Method of Concomitant Variation: phenomena which vary together are connected through some fact of causation. (Blackburn 1983a, p. 269)

It is significant that neither Newton’s nor Mill’s lists are recipes of component activities: they express beliefs, about the nature of the cosmos and appropriate ways to get knowledge of it, criteria for judgements and assumptions.

The Gaia hypothesis as a belief system about Nature

We have discussed already that in the last decades of the twentieth century - described by some writers as the post-positivist era of science and by others as the post-modern era of thought - science has become characterised much more diversely than in previous times. The companion chapter on context and Appendix B.1 note some of these influences as post-modernism, ecology and feminism. As an example, in 1979 James Lovelock proposed that the Earth be considered wholistically, as a superorganism, and not reductionistically, as (western European) science has treated it traditionally. The scientific status of this hypothesis at that time was contentious (Lovelock 1995; Kelly 1988), but in his revised preface Lovelock reasserts that the concept of Gaia is more meaningful in the late twentieth century than the beliefs about Nature embodied in traditional characterisations of science:

On 4 July 1994 the United States of America awarded the Liberty Medal to the Czech president, Václav Havel. In his speech of acceptance he took the theme, ‘We are not alone nor for ourselves alone.’ He recognised that the modern age has ended, the artificial world order of past decades has collapsed and a new more just order has not yet emerged. He went on to say that we are now where classically modern solutions do not give a satisfactory response. We need to anchor the idea of human rights and freedoms in a different place and in a different way than has
been done so far. Paradoxically, he said, inspiration for the renewal of this lost integrity can again be found in science. In a science that is new - post-modern - a science producing ideas that in a certain sense allow it to transcend its own limits. He gave two examples: first, the anthropic cosmological principle where science finds itself on the border with myth which returns us to an ancient idea, namely, that we are not just an accidental anomaly. Second, the Gaia theory in which all life and all the material parts of the Earth’s surface make up a single system, a kind of mega-organism, a living planet. In Havel’s words:

According to the Gaia Hypothesis, we are parts of a greater whole. Our destiny is not dependent merely on what we do for ourselves but also on what we do for Gaia as a whole. If we endanger her, she will dispense with us in the interests of a higher value - life itself.

The statesman Havel’s acceptance that human rights are not enough is timely. Not only for ourselves but for Gaia. (Lovelock 1995, p. viii)

Thus Lovelock argues three things. First, he argues for an alternative belief system for science: belief in Gaia and the attitudes, values and so forth that it entails. Secondly, he argues that such a scientific belief system derives its meaning partly from the context of its time: of ecological, political and social disorder that affect Nature/Gaia as a whole and not just people. Thirdly, he argues that social, political, technological, individual and other contexts can be positively influenced by such a belief system in science.
4. Conclusions for theorising about the science curriculum

This section extends the argument developed in the present chapter, that a science belief system is a necessary part of metascientific characterisations of science, to claim also that it should form part of school Science. The implicit character of belief systems means that they are not only unrecognised commonly in science, but that other belief systems held by an individual or group are also commonly unrecognised. This has important implications for a general school science curriculum, particularly when scientific belief systems conflict with other belief systems held by school students. There is a massive science education literature that addresses the persistence of student ‘misconceptions’ of science after science education courses. The present section will argue that this arises because the curriculum fails to make explicit the beliefs, assumptions, and so forth, that characterise science, and to address conflicts between scientific belief systems and other beliefs held by students.

I. Findings about the nature of science belief systems from the review of the metascientific literature.

There is a range of currently accepted views of science in contemporary scientific, philosophical, sociological, historical and linguistic analysis, that characterise science by various belief systems or elements of belief systems. There is no simple, clear and universally agreed explanation of a science belief system. Examples given in this chapter can be summarised as:

*There is a range of views of science that entail different belief systems*

a) Different accounts of science either mention or entail various beliefs, assumptions, criteria for judgements, values, and so forth, that can be meaningfully interpreted as elements of a belief system.

b) Different metascientific perspectives entail different belief systems in science:

• where knowledge arises from perception, as in empiricism, science may have nothing to say about a material world beyond these perceptions;
• where knowledge is a mental construction, as in constructivism, science may only generate knowledge that is agreed within its social or mental contexts;
• where an external reality is presumed, as in scientific realism, scientific knowledge of it is socially and psychologically constructed.

c) The present thesis suggests that Borhek and Curtis have proposed a useful theory of belief system that comprises several elements:
• values that define what is good or valuable;
• criteria by which statements made within the belief system are validated;
• a set of rules by which beliefs within the system are related to each other, called logic and including language;
• a perspective, or cognitive map or mythology, which defines the individual believers, the group of believers, and the environment external to the believers;
• substantive beliefs, which are the actual content of the belief system, and can only be understood in terms of the values, criteria, rules and perspective of the system;
• prescriptions and proscriptions of behaviours, including norms for behaviour; and
• beliefs about the ways to achieve goals, called technology.

d) Beliefs and other elements of the science belief system are entailed by each of the dimensions of science: knowledge, activity, purpose, context and structure; that is, the dimensions of science each entail beliefs, assumptions, and so forth.

e) Various scientific belief systems have been adopted throughout the history of science, and at any stage, including the present, several systems of belief have been in contention.

f) Any particular characterisation of science chosen, whether adopted consciously or not, entail particular beliefs, assumptions, values and attitudes which will differ from those entailed by other standpoints which have been rejected, whether consciously or not.
Science is characterised by beliefs about cause and effect

g) A scientific world view is characterised commonly as differing from other world views by particular beliefs about cause and effect.

h) Beliefs about cause and effect are not self-evidently true as commonly supposed in either scientific or general contexts, and are disputed in philosophy.

i) Beliefs about cause that are widely held include
   • causes and effects are events that have naturalistic, not supernatural, explanations;
   • causes and effects are events that are connected by causal paths;
   • causes reside in particular entities, not classes, and so particulars are the appropriate subjects of scientific study.

j) Beliefs about cause and effect are commonly underpinned by a belief that the points of space and time are continuous (known as the Law of Continuity), but quantum mechanics describes phenomena that are not continuous in time and space, and thus cannot be explained by beliefs that underpin classical physics and everyday events.

Science is characterised by particular beliefs about, and attitudes toward, the material world

k) A scientific world view is characterised also by beliefs about, and attitudes toward, the cosmos.

l) Characterisations of science use the term nature in two senses, sometimes distinguished, as in the present thesis, by the use of upper case and lower case: Nature as the material world, and nature as the essence of things in the material world; the latter is no longer used widely, and the former is interpreted variously.

m) A significant characteristic of the classical science that emerged in the Scientific Revolution was the demise of beliefs about Nature, notably that
   • Nature was like an organism,
   • Nature had a soul,
   • Nature could be understood and manipulated by magic, and
   • that humans had a special place in, or were separate from, Nature.
Conversely, other beliefs arose about Nature, notably that

- Nature was like a mechanism that could be understood by understanding its parts,
- Nature had no soul,
- Nature could be investigated rationally according to a single, naturalistic logic that applied universally, and
- Humans were part of Nature.

n) An influential characteristic of science is that it can only provide explanations of the phenomena we observe and not inferences about a material world; therefore it rejects metaphysical beliefs about the existence of Nature; this view, the positivist Received View, was dominant for at least the first half of the twentieth century and is still influential as a tendency of thought among many scientists and the public.

o) A perspective in post-positivist metascience is scientific realism, that presupposes an external reality, even if our knowledge of it is socially constructed; it argues that the success of science is meaningful only if we presuppose, or believe in, an external reality.

p) Another perspective in post-positivist metascience is constructivism; weak versions emphasise the social construction of knowledge; strong versions argue that science knowledge is beliefs that are entirely negotiated or constructed within the context of particular beliefs; Knorr-Cetina has argued that this does not deny a material reality, simply that such a reality is continually renegotiated, and the key to understanding science is understanding this negotiation.

q) Another perspective in post-positivist metascience is to challenge beliefs about Nature that arise from the reductionist approaches that have traditionally characterised science; these include some ecological challenges (this chapter mentions the Gaia hypothesis) and feminist critiques (discussed in Appendix B.1).

Scientific and magical beliefs

r) Science is popularly distinguished from magic by differences in characteristic beliefs about Nature, but this is relatively recent in the history of western European
science; it relates to beliefs already discussed, such as beliefs about Nature, and cause and effect and, in turn, about appropriate ways to gain knowledge of the material world.

s) Magical beliefs are interpreted here as beliefs that there is more than one logic of the material world, and that ordinary science knowledge accesses only one logic; other logics may be accessed and interpreted by significant terms, numbers or signs.

t) As the twentieth century progressed, the public faith in scientific rationality, truth and neutrality (beliefs associated with the positivist characterisation of science) lost its dominance; some scientists and science commentators now express alarm that scientific beliefs in effect 'compete' for public acceptance with other beliefs, such as superstitions, that are antithetical to belief systems that characterise science.

Science, Nature and God

u) Science is partly characterised by the interface of sets of beliefs about science, Nature and God; this has been the case throughout the history of science and remains the case today.

v) Several examples of this interface are:

- God constructed an orderly and rational world that shows evidence of design and that can be studied by science;
- God, as the powerful creator of the world, can disrupt its order and cause activity that is beyond human comprehension;
- there is no God, and human life has no meaning for Nature beyond what we construct; science simply gives us knowledge of Nature;
- the existence of human rationality in the universe is not accidental, and means that the universe is self-aware; some sciences seem to indicate purpose in the universe;
- the scientific belief system concerns naturalistic explanations of the material world and has nothing to say about the existence or not or not of any God, which involves super-natural explanations;
the authority of religious beliefs, as revealed in texts or revelations, is
supreme and at best science beliefs are subordinate to revealed, religious
truths.

w) Studies of public controversies concerning science, including those about science
and religion, animal rights, ecological debates, UFOs, and so forth, show the
science community is only one of a number of groups in society that negotiate the
legitimacy of their belief system as part of these disputes.

Nature and mathematics

x) Mathematics has been part of science history from antiquity down to the present,
although different scientific belief systems interpret the role of mathematics, and its
relationship to the material world, differently.

y) In general, the use of mathematics in science 'is predicated upon the belief that the
Universe is algorithmically compressible' (Davies, in summary statement 85), that
is, a belief that Nature can be described using mathematics.

z) In the twentieth century the mathematics in science has become significantly more
complex, helped by the massive increases in computing power; much of this
mathematics describes and predicts phenomena that do not arise from the belief
systems of classical science and everyday understandings.

Other metaphysical beliefs

aa) Classical science interprets the ultimate character of phenomena as particles; much
of twentieth century physics has explored progressively more fundamental
particles within the atom.

bb) Historically, particles were believed to be knowable by primary qualities, such as
shape, position, number, spatial relation and motion, that inhere within the bodies
themselves; so-called secondary qualities, such as taste and feel, were believed to
arise from the observer and so were not the subject of inquiry; this distinction is
difficult and is not resolved.
cc) Some recent physics interprets the ultimate objects of science knowledge in the material universe as fields rather than things.

dd) Some recent, albeit often not mainstream views, such as the Gaia hypothesis, characterise the material universe as systems rather than fields or things.

ee) Recent developments in physics, for example, challenge our conventional beliefs about being (ontological beliefs): quantum cosmology, imaginary time, chaos theory, self-organising systems, superstring theory, and advanced theories of complexity and computation.

*Beliefs about experimentation*

ff) While experimentation is not the only scientific activity, experiments are characteristic of science and are justified by a general belief that designed interventions in Nature generate knowledge of it.

gg) Further, science experiments rely on the belief that ‘the conditions for producing a given effect can be separated into independently variable factors, in such a way as to demonstrate how the factors studied - and represented in experimental design and dependent and independent variables - retain their identities (and dispositional properties)’ (Bhaskar 1983c, p. 136)

*Models and metaphors*

hh) Science is characterised by the use of models and/or metaphors to interpret or represent natural phenomena; the use of models and metaphors rests on a belief that they characterise the phenomena being investigated.

ii) Organisms, mechanisms, particles, fields and systems have all been used as models or metaphors to explain the ultimate character of Nature.

*Other belief systems*

jj) Western European science is characterised sometimes by contrasting its belief system - its fundamental assumptions, beliefs, and so forth - with belief systems in other cultures.
There are fundamental problems in making comparisons between belief systems that need to be recognised, mentioned generally in the companion chapter on context and discussed in Appendix B.1.

In addition to the general difficulties of cross-cultural comparisons, recent studies from several fields argue that comparisons between belief systems are more difficult than traditionally recognised: there can be a tendency to assume the efficacy of the elements of one’s own belief system, while at the same time failing to identify the elements of other belief systems.

Some beliefs that have been used to distinguish modern western European science from other natural philosophies are

- belief that the universe is a god or deity, or a manifestation of one
- belief that events in the universe are cyclic, or recur, such as reincarnation
- belief that the universe is an organism or animal
- belief that the universe is capricious, non-uniform, unpredictable and therefore unknowable by humans.

These accounts characterise the attitude or orientation that arises from such beliefs as one of bewilderment or complacency, and not the attitude of inquisitiveness that characterises western European science.

Some beliefs in other cultures have been the same as those that characterise western European science, for example the Mohists and Legalists in ancient China, but they did not endure; one of the reasons suggested is the different social contexts in which competing belief systems were negotiated. Some attitudes, such as awe or bewilderment, are also found in accounts of various natural philosophies. However, where Davies (1992), for example, described a sense of awe as a stimulus to further inquiry, others such as Jaki (1974) described awe in non-western contexts as stifling inquiry.

**Belief system is a necessary dimension of science**

A belief system, as discussed in this chapter, is a necessary dimension of science because discussions in the literature about science characterise science partly by
appealing to belief systems or their elements, and those arguments would fail without doing so.

**Belief system is interrelated with the other dimensions**

qq) The belief system is interrelated with the other dimensions - knowledge, activity, purpose, structure and context - meaning that it is not an entity that can stand alone, but one of six foci or perspectives which are used in combination to characterise science.

rr) The belief system is interrelated with the other dimensions in the sense that beliefs and other elements of a belief system are entailed by statements about knowledge, activity, purpose, and so forth.

ss) Aside from beliefs concerned with these other statements, however, science is characterised by beliefs about the material world that it studies (ontological beliefs), the character of our knowledge of that world (epistemological beliefs), and about the way in which science develops such knowledge (methodological beliefs).

**II. Implications for a school science that is grounded in the metascientific literature.**

Any characterisation of science entails a system of beliefs, as the present chapter has argued at some length, and this dimension of science is significant for the general school science curriculum in two broad senses. First, belief system is a necessary dimension in characterising science, and secondly that the identification of belief systems in science provides a significant insight into the belief systems of school students (and others) as they attempt to learn science.

**The implication of scientific belief systems on the school curriculum**

The present chapter has argued that when we examine the scientific and metascientific literature we find that science is characterised partly by a belief system. Further, these characterisations fail if they do not entail a belief system, whether or not any particular
account makes it explicit. Therefore the present thesis argues that a robust characterisation of science in the school curriculum should make explicit various beliefs, assumptions, values, and so forth - the elements of the belief system - that characterise science. To present science as neutral, value free and objective, for example, whether intentionally or simply by omission, is to present a highly contentious characterisation of science that will fail some future citizens as they seek to evaluate some future claim made in the name of science. For one thing, disinterestedness and objectivity are elements of a particular belief system that should be identified. For another, the present thesis includes elsewhere metascientific argument that in any case pure, disinterested scientific research is in the minority at best, and a spurious notion at worst. While many would characterise pure (as distinct from applied) science as aiming to be objective and neutral, this is better characterised as a goal, purpose or intention and rather than a description of actual practice. Equally, many would argue that objectivity, while a goal, is negotiated and relative, and that this goal is best met by identifying the assumptions, beliefs, values and criteria made by scientists and others.

There is both individual and community benefit from the school science curriculum addressing scientific and non-scientific belief systems. Theoretical disputes within the scientific and metascientific communities have traditionally been judged to be of little or no interest to many lay citizens. It is especially the case in public disputes that involve citizens, industries and government instrumentalities, and where scientific claims are made. Here the assumptions, values and criteria for judgement can clearly affect the outcomes - knowledge claims - and are evident if we know to look for them. To be unaware that science entails a belief system is to fail to understand the basis for scientists making the judgements and assumptions that they do; moreover, it is to fail to defend or justify certain beliefs, values, and so forth, when confronted with competing claims. The Creationist-evolution debate in science education is an example where the basis for the difference between these two, opposing views of science for schools is two belief systems that are mutually incompatible in significant respects. For example, Strahan (1987, pp. 5-9) characterises science partly by a set of criteria and beliefs, such as the uniformity of Nature, naturalistic cause and effect,
falsifiability, tentative or revisable claims to knowledge and truth, testability, limited respect for authority. He rejects ‘Creation science’ partly because, from his review of creationist literature, he identifies beliefs and criteria that are incompatible with those he used to characterise science: the creation of Earth and some extraordinary phenomena had non-natural causes (direct action by God), meaning that Nature was not uniform and not all causes were naturalistic; and the authority of a particular Scriptural interpretation is unquestionable and incorrigible, therefore its truth claims are absolute and not falsifiable or revisable. Thus while these opposing views share some characteristics, such as particular concepts and a limited interpretation of scientific activity, the fundamental and significant differences are characterised well by their different belief systems.

Given the extensive discussion in the present chapter, a full debate on scientific belief systems would be much longer. That would not serve our purpose. Rather, a few points should be made clear in summary.

- We can engage in debate about beliefs, but the full argument is best made using the concept of the belief system, rather than seizing on individual beliefs in isolation.
- Systems of belief used in science need to be understood in reference to other dimensions of characterisation, such as activity, context, purpose and knowledge.
- The notion of scientific belief systems can be difficult to identify because (a) beliefs, assumptions and the like are, almost by definition, typically unstated and part of our unconscious thought, and (b) it goes against the familiar, positivist characterisation of science as being rational (and therefore conscious) and objective (and therefore free of assumptions, emotions, and so forth).

Belief system as a dimension both of science and students of science

The second argument for addressing scientific belief systems arises from the first, and it is a learning issue: the influence and resilience of each student's own personal beliefs. We have noted in the literature review that probably the largest body of recent and current science education research concerns students' construction of meaning, showing that children's prior conceptions are often at odds with accepted scientific explanations and beliefs, and can be resistant to change. The present thesis argues that this is not adequately
explained simply in terms of knowledge, such as conceptual change. Rather, children, and for that matter all people, hold beliefs about how the world works, and their belief system makes sense to them. In pointing to what he calls the *unnatural nature of science*, Wolpert (1992) highlights the fact that many scientific beliefs and explanations are counter-intuitive; that is, they run counter to common sense. (We might argue that many scientific beliefs and explanations are commonsensical, but Wolpert makes a plausible case that many are not, particularly for those without a science education). Thus we can find in the literature examples where students have an Aristotelian view of motion - that objects move only while a force acts on them - or a belief that God can cause unexpected and unnatural events, and that such beliefs can be highly resistant to traditional science teaching. The present thesis argues that it is the student’s personal belief system that is resistant, and it is so because it is meaningful to the student: it comprises their personal world view. Thus simply being told that science has found otherwise, or doing some sample activities designed to show otherwise, does not address the student’s unidentified and implicit beliefs, values, assumptions and so forth. To cite the Creationist-evolution controversy again, the literature shows that a significant proportion of science students, both at school and university, will maintain a belief in literal creationism and a disbelief in evolutionary theory despite their science studies (Matthews 1994, p.30).

This second argument raises an ethical question of whether or not a science education should work towards forming particular beliefs in children. For example, we have noted in the present chapter Nelkin’s (1995) observation that the individualistic culture in the US has fostered a view of individual rights to belief, and that if parents wish their children to have particular religious beliefs, the education system has no right to indoctrinate students (as they would see it) in some other belief system.

The present thesis argues that there is a distinction between education and indoctrination, on the basis that an educated person should be better able to discern different points of view and make considered judgements between them, whereas an indoctrinated person will be aware of only one view, or have charicatured impressions of alternative views, so that indoctrination is likely to lead to a particular and uncritical view. On this
basis, the present thesis accepts the criticism, put by some Creationists and others, that traditional school science puts only a particular view of science that characterises science knowledge as uncontested, even uncontestable, and as given. Such an approach entails an uncontested, given belief system. This is at odds with a commonly given rationale for science education, that it promotes critical and rational thinking. The solution, given the discussion in the present chapter, is to make explicit the assumptions, beliefs, criteria for judgement, and so forth, that scientists use; that is, the belief systems used. This will mean addressing examples where scientists use different belief systems, as when they make different assumptions or make different judgements. It could be illustrated also by historical belief systems, such as by contrasting Aristotelian and Newtonian mechanics. It will also mean addressing examples where a belief system is not accepted as scientific by the scientific community: as we have seen in the foregoing discussion, science belief systems are sometimes made clear by examining differences from other belief systems.

It is in this way that students can understand the special sense that science knowledge is considered tentative yet authoritative. There seems to be a fear on the part of some in the science community that the lay public cannot understand this, and presumably will interpret tentativeness as simple relativism: that any viewpoint is as good as any other, as argued in extreme externalist or constructivist views. Such views fail to account for the undoubted successes of science: scientists are able to make impressively accurate predictions, and sometimes control, of natural phenomena, as when they put satellites and space probes into predetermined orbits, or synthesise completely new chemicals with predicted properties, and so forth. Clearly these involve successful assumptions, judgements and so on. That they are tentative is a belief itself, and there are many examples from science history where a successful belief system is replaced by a more successful one: the replacement of classical Newtonian mechanics by relativity and quantum mechanics is a common example, but one which is rarely made clear at less than undergraduate levels of study. The present thesis argues that this approach is not indoctrination, because it explicitly addresses what scientists and others mean to think critically, and makes clear the role of a belief system in making judgements, in revising their beliefs, and in maintaining their beliefs. It also is a
means of making clear why some other belief systems, that are not accepted by the scientific community as scientific, may nevertheless be legitimate belief systems in other contexts. Indeed, the general curriculum is predicated on this notion: children study science along with literature, history, art, and so forth, each of which entails particular but different beliefs.

The solution proposed for issues like these - characterising science more robustly, addressing students’ own beliefs, justifying scientific beliefs in the face of competing belief systems in the community, and answering allegations of indoctrination - is to embrace scientific belief systems in the science curriculum. Students should, over the course of their science education, become aware of the nature and diversity of belief systems. Only in this way will they, as future citizens in a scientific and technological society and, for an increasing proportion, as future scientists and technologists, be able to identify and make informed decisions about, scientific belief systems and their interaction with other belief systems.

Some specific recommendations corresponding to the summary of findings in part I above:

Throughout the following, students should develop an appreciation of science belief system as part of developing a multidimensional characterisation.

Science is characterised by belief systems in a variety of ways

a-b) School Science should make explicit how science is characterised by belief systems. For example:
   • Students should develop an appreciation of the various ways in which belief systems, and elements of belief systems, characterise science.
   • Students should develop an appreciation of scientific beliefs and assumptions about the material world and how to gain reliable knowledge of it, such as the role of perceptions, mental constructions, and assumptions about the existence or not and nature of an external reality.

c-d) Students should gain an appreciation of the notion of a belief system, such as an interactive set of: values the define what is worthwhile; criteria used in making
judgements; rules that govern beliefs, including logic and language; a perspective or mythology that sets apart the believers from the non-believers; the substantive (content) beliefs of the belief system; norms (prescriptions and proscriptions) of behaviours; and beliefs about the ways to achieve goals.

e-f) Students should gain an appreciation of different past and present belief systems and how they differ.

Science is characterised by beliefs about cause and effect

g-j) School Science should provide students with opportunities to develop an appreciation of scientific beliefs about cause and effect. For example:

• Students should develop understandings about naturalistic, supernatural and preternatural accounts of cause and effect, and that science accepts naturalistic explanations only.

Science is characterised by particular beliefs about, and attitudes toward, the material world

k-q) School science should provide students with opportunities to develop an appreciation of past and present beliefs about the cosmos, or Nature, or the material world, including: Nature can be explained by a single, universal, uniform logic; and humans are part of Nature.

Scientific and magical beliefs

r-t) School Science should provide students with opportunities to compare the characteristics of science and magical, paranormal and other beliefs, and to appreciate that sometimes there are difficulties in making these distinctions.

Science, Nature and God

u-w) School Science should provide students with opportunities to characterise interfaces between scientific beliefs and religious beliefs. For example:

• Students should develop an appreciation of the nature of scientific beliefs about the material world, the use of naturalistic explanations, and the interaction of scientific beliefs with other dimensions such as purpose.
• Students should have opportunities to contrast a multidimensional characterisation of science with religious and other belief systems; this should be done sensitively, like any comparison of beliefs, so as not to set science in opposition to the beliefs of the students or their families, but to clarify the strengths and limitations of science and of other belief systems.

Nature and mathematics

x-z) School science should present students with opportunities to develop an appreciation of the beliefs that underpin the use of mathematics in science, that is, beliefs about the mathematical characteristics of the material world. It should not presume a mathematical approach to school Science, but rather develop it.

Other metaphysical beliefs

aa-ee) School science should provide students with opportunities to develop an appreciation about other metaphysical beliefs that are part of, or characterise, scientific belief systems, such as: beliefs about the ultimate character of phenomena, such as particles, fields and systems; qualities, such as primary, secondary and occult qualities; and some recent notions such as chaos and self-organising systems.

Beliefs about experimentation

ff-gg) School science should provide students with opportunities to develop an appreciation of beliefs that underpin the use of experimentation in science, notably that the nature of the material world is such that in many situations variables can be isolated and studied because they retain their identities or properties.

Models and metaphors

hh-ii) School science should provide students with opportunities to develop an appreciation of the roles of models and metaphors in science to interpret, characterise or represent natural phenomena. For example:
• Students should have opportunities to identify, experience - first hand or through case studies as appropriate - and discuss a variety of models and metaphors used in science, such as mechanisms, organisms, particles, fields and systems.

Other belief systems

School science should provide students with opportunities to develop an appreciation of other belief systems, meaning both the belief systems of non-western European natural philosophies, and non-science belief systems within western cultures; it should use a multi-dimensional characterisation of science to do this. For example:

• Students should gain an appreciation of the role of belief systems in contrasting western European science with other natural philosophies, such as the rejection of supernatural, cyclic and organistic beliefs, and the belief that Nature is uniform, predictable and therefore knowable.

• Students should gain an appreciation of the role of belief systems in contrasting western European science with other belief systems, such religious, 'new age', superstitious and social belief systems.

• Students should gain an appreciation of the difficulties in comparing belief systems; that one presumes the soundness of one’s own beliefs and discounts other beliefs.

Belief system is a necessary dimension of science, and is interrelated with other dimensions

School science should provide students with opportunities to develop an appreciation that belief system is a necessary dimension of science, and that is also necessarily just part of the multi-dimensional character of science.
Purpose, as in directedness according to aim, goal or intention, is a necessary, but not sufficient, dimension of science.

Introduction

This chapter comprises an argument that purpose is a necessary, but not sufficient, dimension of science. Purpose is defined generally, as plan, aim, goal or intention:

*Purpose*

(1) the object for which anything exists or is done, made, used, etc.;
(2) an intended or desired result; end or aim;
(3) intention or determination. (The Macquarie Dictionary).

The argument, that purpose is a necessary dimension of science, is that characterisations in the metascientific literature are incomplete without it, and it does not reduce to any of the other dimensions, i.e. its omission is not covered by any of the other dimensions. It is not a sufficient dimension of science in that it does not completely characterise science. Where science is characterised in the literature by purpose, usually it is characterised also by one or more of the other dimensions of science: knowledge, context, activity, structure and belief system. These other dimensions may be used in explicating scientific purpose, and scientific purpose may be used in explicating the other dimensions.

The introduction to the present thesis acknowledged the stimulus of Millar and Driver's argument for purpose as a dimension or characteristic of science:

For science, we would argue, is characterised by its concepts and purposes, not by its methods. (Millar & Driver 1987, p. 56).

Unfortunately, Millar and Driver did not provide an argument for this claim beyond this assertion. Instead they argued that science teaching is characterised by knowledge and purpose, and that emphases on process science in education are misplaced. The present chapter argues that the metascientific literature does indeed characterise science by purposes, but as part of a multidimensional characterisation. The other part of Millar and
Driver's claim, that processes do not characterise science because they are not unique to it, is addressed in the companion chapter on activity.

As with each of the companion chapters addressing the dimensions, this chapter and Appendix B.3 will use arguments from the literature selectively. In so doing it will attempt to strike a balance between including sufficient detail to demonstrate the argument and not repeating all the detail given in the literature.

The argument in this chapter comprises four parts, as set out in the introduction to the six companion chapters:

1) evidence from the analysis of the summary statements;
2) evidence from argument in the metascientific literature;
3) the relationships between the dimension purpose and the other dimensions;
4) conclusions for use in theorising about the science curriculum.
1. Evidence from the summary statements

The collection of classes (in Table A.5) and text units from the differentiae (column four of Table A.9, headed Purpose), collectively indicate that science is characterised partly by intentions, ends, aims, goals or purposes. As with the other dimensions, this category of characterisation was constructed from a semantic analysis of many metascientific sources. Thus it includes a wider range of viewpoints than do many individual accounts in the literature.

Purpose is not usually the central dimension in the summary statements, but nonetheless is embedded commonly in them. Thus even in accounts that are not framed around an explicit notion of purpose, there is an implicit recognition that scientific activity is not aimless or (usually) serendipitous, and is guided by short term objectives or long term aims. This was recognised by the philosopher Karl Popper:

To speak of 'the aim' of scientific activity may perhaps sound a little naive; for clearly, different scientists have different aims, and science itself (whatever that may mean) has no aims. I admit all this. Yet when we speak of science, we do seem to feel, more or less clearly, that there is something characteristic of scientific activity; and since scientific activity looks pretty much like a rational activity, and since a rational activity must have some aim, the attempt to describe the aim of science may not be entirely futile. (Popper 1956, 1983, p. 132)

Note that Popper presents a twofold characterisation by purpose. The first is speculation about an aim of science, where he initially rejects a scientific aim, but seems to conclude that aim or purpose is implicit in the claim that science is rational. The second is a clear identification of the aim-directed activity of individual scientists.

Despite Popper's somewhat tentative tone, some summary statements explicitly mention purpose, goal or aim, as given in Table A.5. The following quotations from summary statements are examples of explicit characterisations by purpose:

[Science is] all exploratory activities of which the purpose is to come to a better understanding of the natural world. (Medawar, in summary statement 3; emphasis added)

Among the characteristics that distinguish science from other fields of human endeavour are the goal of explaining, with ever increasing precision, the nature of the universe in terms of uniform natural processes and relationships, and the commitment to the testing of proposed explanations by means of empirical
observation and experimentation. (National Academy of Sciences of USA, in summary statement 5; emphasis added)

The goals and objectives of the tradition are twofold, namely, to predict and control phenomena revealed by the metaphysics and epistemology of the paradigm, and to explain and understand these same phenomena. (Gale, in summary statement 20; emphasis added)

The aim of science is to attempt to comprehend the world rationally, as we all agree (including the positivists who should disagree). (Agassi, in summary statement 43; emphasis added)

These goal states concern themselves with certain interesting epistemic and pragmatic attributes. Consider a typical list of some of these aims:
a) to acquire predictive control over those parts of one’s experience of the world which seem especially chaotic and disordered;
b) to acquire manipulative control over portions of one’s experience so as to be able to intervene in the usual order of events so as to modify that order in particular respects;
c) to increase the precision of the parameters which feature as initial and boundary conditions in our explanations of natural phenomena;
d) to integrate and simplify the various components of our picture of the world, reducing where possible to a common set of explanatory principles. (Riggs, quoting Agassi, in summary statement 58; some emphases added)

Those theories which we come to call ‘scientific’ are efficient at advancing our cognitive aims and, in general, they do so better than theories we denote as ‘non-scientific’. (Riggs, in summary statement 58; emphasis added)

Other statements indicate purpose in the wording, although they do not use explicit terms such as purpose or one of its synonyms. Purpose is commonly indicated by the prepositions to, expressing ‘aim, purpose or intention’ and less frequently for, meaning ‘with the object or purpose of’ (The Macquarie Dictionary).

What is relevant to a scientific problem and what has meaning in science depends on what we are looking for and what we are trying to accomplish. (Grünfeld, in summary statement 29)

Research ... is very often conducted toward the finding and the testing of metaphysically relevant hypotheses. (Agassi, in summary statement 41)

Below is a sample arbitrarily selected from the first twenty summary statements, roughly grouped to indicate some variety of purpose:

* to perceive, describe, comprehend the cosmos
  * to come to a better understanding of the natural world  (3)
  * to increase understanding (8)
  * to form a picture of reality (15)
• to establish [the] connections between [this picture] and the wide world of sense impressions
• to form conceptual generalisations about the many particulars of empirical evidence
• to make the chaotic diversity of our sense experience correspond to a logically uniform system of thought

_to understand, explain_

• to explain (5)
• to explain the world around us (4)
• to produce a satisfying explanation of reality (8)

_to have greater understanding than that of one's own experience_

• to extend experience (2)

_to seek patterns, regularities, causes_

• to reduce experience to order (2)
• to acquire and organise knowledge (about the universe and its parts) (5)
• to explain the interaction and interrelationship of those parts (through the formulation of laws and theories describing natural processes) (5)
• to generate understandings codified in statements of high generality (laws and principles) and accessible to experimental tests (8)
• to verify or falsify claims about the world (14)
• to produce and distribute knowledge (18,9)

Note that the loose clusters above are not intended as discrete categories, but simply to indicate something of the scope of purpose as used in the literature. Variations in the notion of purpose are the subject of the remainder of this chapter.
(2) Argument from the metascientific literature

Debates in the metascientific literature address many aspects of purpose in science, which again support a broad interpretation of scientific purpose. This scope is indicated by the review of the following metascientific arguments in Appendix B.3.

B.3.1 Current metascientific views with respect to purpose

Metascientific interpretations differ partly in the purposes they ascribe to science. These are summarised in Table B.3.1.

B.3.2 The role of purpose in characterising a western European scientific tradition

Historical accounts of science partly characterise the western European scientific tradition by scientific purposes. These have included seeking naturalistic explanations, control over Nature and other goals discussed in Appendix B.3.

B.3.3 Purpose as seeking solutions to problems, reliable knowledge, regularities, causes and other ends.

Most accounts of science appeal to more than one notion of purpose, including seeking solutions to problems, reliable knowledge, regularities and causes. Each of these is complex, and appeals are typically made to more than one of these, and other, goals at the one time. Some particularly enduring and influential goals are dealt with separately in later sections.

B.3.4 Control of Nature as a purpose of science

A pervasive theme in the literature is that science is the means by which humanity gains control of Nature: that through accumulating reliable knowledge of Nature we are better able to explain, manipulate and make ever more reliable predictions about it. Thus knowledge, explanation, manipulation and prediction can be characterised as intermediary goals by which we can achieve the higher goal of control.

B.3.5 The strengthening of utilitarian purposes in the twentieth century
During the twentieth century science became increasingly characterised by utilitarian purposes that reflected its increasing association with government, industrial, economic and military goals.

B.3.6 Critical perspectives on scientific purposes

The increased sharing of scientific, economic, industrial and other goals, mentioned in the section above, point to the inadequacy of purely cognitive goals in accounting for the nature and direction of scientific goals and the nature of science knowledge itself. This is reflected in critical perspectives to science. It also has strong implications for the interaction of the public with science communities and institutions, particularly in contemporary pluralistic democracies.
Purpose as a necessary dimension of science

The argument to this point of the chapter shows not only that the metascientific literature characterises science by purpose, but it does so in a variety of ways: it identifies various purposes, usually together. Thus natural science is characterised as an enterprise which is directed to one or more of the goals of seeking knowledge of Nature, solutions to problems, regularities in natural phenomena, causes of phenomena in Nature, various intermediary goals by which other goals can be achieved, controlling Nature and usefulness to people. Simply identifying purposes does not, of course, make purpose a necessary dimension of science. Instead, the argument for the necessity of purpose arises from the roles it plays in characterisations in the literature.

First, the accounts presented in this chapter characterise science as being carried out to some end in an absolute sense. Science is not serendipitous, at least not in a strategic (long term) sense. (The literature does record instances of apparent tactical, or short term, serendipity, but these are always set within a longer term context that is clearly aim-directed. Hence the maxim, *Chance favours the prepared mind.*) Thus it is inconceivable that an experiment could be set up in the complete absence of any purpose: even just the preparatory selection, setting up and calibration of equipment, for example, is nonsensical unless particular outcomes are sought.

Secondly, the accounts presented in this chapter characterise science as being carried out to ends in a relative sense: to certain ends and not others. This is not as clear cut as was once thought, but the very tension in arguments about what are scientific purposes (*vis a vis* purposes of the non-scientific) are central to understanding disputes involving science, notably those in the public arena. It is relatively unproblematic where the goals of science are identified as arising from the field. Thus for cognitive/knowledge goals, as in internalist views, the scientist pursues goals identified from the cognitive field - predominantly through the specialist literature. They are not, for example, personal ones, as identified in some critiques of the work of Sir Cyril Burt. Burt’s work has been characterised as unscientific because it did not seek (aim) to meet accepted scientific
criteria and, in some critiques, because the falsification of data pointed to personal aims concerning status, and so forth (Gieryn 1995, pp. 432-3).

It is unproblematic to use goals in this way to characterise science as different from some other fields of human endeavour: science does not work towards rhyming or cadence as does poetry, for example. It is still relatively unproblematic in Kuhn's characterisation of normal science, comprising problem-solving within an existing paradigm: goals are identified from the paradigm. Revolutionary science, in which a paradigm is overthrown, also draws its aims from the field: the common example of Einsteinian mechanics overthrowing the Newtonian paradigm can be characterised as changing the attempt to address the same (explanatory) goal.

Tension arises, however, when there is dispute or confusion as to whether the goals are characterised as emerging internally, from the scientific community, or not. Judgements about this status are no longer thought to be as clear cut as they were once characterised, and a good deal of the STS literature addresses issues related to this (Gieryn 1995). For example, the goal of democratic participation - universal franchise - is readily identified as arising within the field of politics. In traditional characterisations, science proceeds by consensual arguments of various sorts, but does not require - indeed it rejects - a goal such as universal franchise.

The exclusion of democratic participation results because the principle of persuasion in science works by appealing to evidence and argument: scientists aim to collect evidence and construct arguments that are based on it and meet certain criteria. Thus the resolution of a scientific matter is not made by a show of hands at a public meeting (although a socio-political matter may well be): unlike a political democracy, one is not entitled to vote in establishing a scientific consensus by virtue of birthright or age. Of course, it is the acceptance of evidence that, in principle, ultimately wins the day, and this is taken often as some demonstrated capacity for relevant expertise. It is following this line of thinking that most people seem to be confident in identifying science: the complex of goals characterising science underpin the general autonomy of science and contrasts strongly with most of what is agreed to be non-science (Porter 1990). Yet we have seen from the
selection of critiques in section 3.6, above, that the nexus between government, industry and much of science (the scientific community) commonly devalues the scientific authority of community groups who oppose various pronouncements that the established scientific community labels as *scientific*. Clearly, to win the scientific argument (putting aside the political argument), successful community groups have been able to demonstrate the validity of their alternative knowledge claims in part by demonstrating scientific purposes.

Further, the present thesis suggests that at least some debate in the public arena that draws on science can be characterised by goals that are incompatible because they represent different but not widely accepted ‘scientific’ purposes. For example, the present author has observed a number of public debates that purported to concern scientific matters but the show of hands by the voting audience at each meeting resolved nothing concerning science. One meeting involved the geologist Ian Plimer and the ‘creation scientist’ Duane Gish, and another involved an ecologist and a pro-logging contractor. In a strictly scientific sense both meetings were futile exercises. First, the show of hands at a public meeting says nothing about experimental support or otherwise for some claim. Secondly, each speaker argued towards different ends. For the geologist the purpose was to show that geological phenomena conformed to existing scientific understandings and experimental test, but the ultimate purpose of his opponent was to show conformity to an interpretation of biblical texts. For the ecologist the purpose was to show conformity to ecological research over the long term, but for his opponent it was to show the economic impact on the local community over a shorter term. The proponents at both meetings, and arguably much of the audience, went home at the end no closer to resolving the (internalist) *scientific* nature of the disputes. The research on scientific knowledge, controversy and public decision making, reviewed by Martin and Richards (1995), shows that such outcomes should be no surprise. The present thesis argues that an understanding of the various purposes of the different actors is necessary both to understand these issues, and therefore to develop resolution strategies.
The arguments above entail that purpose is a necessary dimension of science: science is characterised by purposes and is inconceivable without them, and these purposes differ in at least some respects from the purposes of other human endeavours. Both of these notions of purpose are found widely in the metascientific literature, and to omit reference to purpose from these accounts would eliminate a category of meaning that does not reduce to belief system, knowledge, activity, structure, or context. Further, different views of science propose different purposes, or different variants of a purpose. An understanding of these differences is significant in developing the capacity to critique different views of science. To recognise only a single position, when there exists a substantial academic literature of debate, is to fail to understand that there may be plausible alternatives, to miss insights provided by alternatives, and especially to be unable to defend a particular view from the attack of other views. One cannot appreciate the certainty or strength of a particular view without appreciating the strength of alternative arguments¹. It follows that to understand science, one must: first, understand the nature of scientific purposes; second, appreciate that accounts of scientific purposes differ; and third, appreciate the insights of some alternative characterisations.

¹ Note J. S. Mill’s classic statement of this position in his On Liberty (1848).
3. Relationships between the dimension of purpose and other dimensions

Purpose, belief system and context as ideology

While section 3.5, above, relates purpose to the context of the twentieth century, the critical perspectives given in section 3.6 imply that this relationship involves more than simply utilitarian purposes. Critical perspectives arise from the interplay of several dimensions: the system of beliefs, the purposes of science, and the social-political-industrial-military contexts, particularly as emerged in the twentieth century. For example, in his discussion of science, alienation and oppression, Young (1990) related scientific developments to scientific and social purposes, and these in turn to individual and social consequences. He argued a critical perspective in which a variety of fields - phenomenology, existentialism, the sociology of work, the histories of colonialism, racism, imperialism, patriarchy and feminism - are united by their intersection with the scientific world view that dissociates the knowing subject and the known object:

The close interrelations between the development of scientific instruments and theories in astronomy, navigation, ballistics and mining, as well as between medicine, agriculture and the study of living phenomena; the development of world trade, mercantile capitalism and urbanisation; and the development of a view of the relations between God, the individual and the redemptive value of work are all so intertwined and mutually constitutive that the scientific, capitalist and Protestant revolutions of the sixteenth and seventeenth centuries are a single reconstitution of the world, the world-view and the structure of relations among people and peoples. They have in common a splitting-off of moral value, mind and responsibility - concerning purpose or final causes - from the labour process itself. This occurs in science, in manufacturing and in moral relations. A mechanical world-view comes to replace an organismic one. Fact and value, thing and purpose and body and mind become sharply dichotomised, just as labour power gets separated off from the worker.

In this way, abstraction from science and from nature becomes the rule, so that what matters is not the sensuous particularity of persons, processes and things but the value of labour power and of commodities. The same alienation occurs in the scientific world-view. What matters to science is that which is amenable to mathematical handling - matter and motion. These preoccupy the thinkers who are developing the modern world-view. The commodity exchange abstraction, like the abstractions of science, treats objects as shorn of their secondary qualities and the social relations embedded in them and in which they have their being. Both are forms of misplaced concreteness. (Young 1990, p. 890)

Young argues that in the industrial revolution the link between the scientific world-view and the daily lives of people was made when scientific and technological rationality was
applied to manufacturing processes. Drawing on argument from Marx, Marcuse and others, the argument is extended to show how this union displaced craft work with control by quotas, which were in turn displaced by control by machines. Thus science was linked to oppression through ideology, a linkage that persists:

Which example should one choose? Here are some candidates: the role of military research through 'research and development' from nuclear physics to higher mathematics, optics, chemical and biological warfare, containerisation and high resolution photography; the management-based research and development policies pioneered by the Rockefeller Foundation including the international organisation of hygiene and tropical medicine, the Green Revolution, primatology, the social sciences and molecular biology; behavioural control in drugs (an industry providing a topic in its own right), conditioning, cerebral implants and psychosurgery; management sciences and operational research; the new technologies and property relations of genetic engineering, fertilisation and childbearing; and, finally, Social Darwinism in international relations, in business and in social theory. I trust that the large domain of the concepts of alienation and oppression vis-à-vis science will begin to become apparent. (Young 1990, p. 895)

Of course, many would retort that this scathing critique characterises the ideological application of science, and not science itself, which comprises only the 'technical' (not social or other) concepts and knowledge-developing activities. This reply supports Young's argument exactly. Young is arguing that a characterisation of science that allows only goals from the cognitive context is too narrow to explain why certain fields of scientific knowledge are pursued, and not others. However, we can explain the direction and social consequences of scientific activity when we identify certain purposes and beliefs being used, which we may summarise as ideology.

Purpose and structure

The companion chapter on structure and Appendix B.4 discuss disciplines and faculties as characteristic scientific structures. In the present discussion of purpose it should be noted that these structures serve identified, traditional purposes of seeking knowledge. Thus scholars with related expertise work together on related cognitive goals in biology, organic chemistry, inorganic chemistry, and so forth. Recent studies, mainly in STS, have identified other purposes for these structures. For example, heads of departments and research centres seek funding and other support on behalf of their units,
partly for knowledge goals but also for strategic and resourcing goals (Cozzens and Woodehouse 1995; Etzkowitz & Webster 1995; Elzinga & Jamison 1995).

Interplays between characteristics, such as the example above involving purpose, belief system and context, or purpose and structure, show that while purpose is a necessary dimension of science, it is not sufficient alone to characterise science. Again, the separate discussions of purpose and the other dimensions are to make the analysis clear; the complete characterisation emphasises the interrelatedness of the six dimensions of characterisation.
4. Conclusions for theorising about the science curriculum

This section extends the argument given in the present chapter, that scientific purpose is an integral part of metascientific characterisations of science, to claim also that it should form part of school science. This argument is based on several premises. First, the preceding argument in this chapter has shown that purpose is a necessary but not sufficient dimension of science in the metascientific literature. Second, although the literature explicitly mentions scientific purpose relatively rarely, it frequently refers to purposes or aims in the wording of arguments; that is, notions of purpose are embedded in the text, or implicitly worded. Nonetheless, despite occasional examples of serendipity or chance contributing to some breakthrough, all characterisations argue that scientific activity is, overall, purposive or goal-directed: all outcomes arise from goal-directed or purposive activities and structures.

Scientific purposes are more diverse than some individual characterisations of science address. For example, most accounts acknowledge publication of articles in scientific journals and texts as a goal associated with the production of knowledge, but they vary in the significance and role of this as a goal. Also, changes in goals lead to changes in outcomes, and the increasing complexity of contemporary science means that many of the world's scientists do their work to meet a broader range of goals than the narrow cognitive objectives given in traditional accounts of science such as positivism. Because the present thesis concerns not just the science education of potential scientists but of all students as future citizens, it concerns also the public understanding of science. The public understanding of and interaction with science rests largely on an understanding of contemporary goal complexes, and access to the determination of goals. To understand science it is necessary to understand (a) that science arises from, and develops towards, a variety of purposes, and (b) how these purposes shape science and different perceptions of it.
I. Findings about the nature of science purposes from the review of the metascientific literature.

There is a range of currently accepted views of science in contemporary metascientific analysis, that characterise science by various purposes. There is no simple, clear and universally agreed account of scientific purpose, but most accounts identify as a central goal the creation of knowledge that meets internalist criteria, such as agreement with experimental test; with the decline of positivism, the goal of certain knowledge is no longer current. The present chapter has argued that current metascientific views can be distinguished by their characterisation of scientific purpose, although there are some similarities between certain views. Many accounts identify some externalist as well as internalist goals, characterised either as the application of internalist knowledge, or as the outcomes of the partly externalist character of science. Examples given in this chapter can be summarised as:

* A range of currently views of science, accepted by various groups of scholars and others, characterises science by various notions of purpose.*

a) Purpose is often implicit, or at least understated, in the wording of metascientific arguments.

b) The influence of the positivist RV meant that for much of the twentieth century the purpose of science was characterised narrowly as cognitive goals concerning certain knowledge of phenomena; the cognitive goal of generating knowledge with as high a degree of certainty as possible remains a goal of science identified by most post-positivist accounts.

c) The goal of generating knowledge is characterised differently in different metascientific accounts: as conforming to observations in empiricism; as arising from mental activity or constructs in constructivism; in scientific realism it is given in an external reality, but constrained by social, psychological and other factors.
d) While acknowledging the goal of acquiring knowledge, various accounts emphasising related or other goals: to generate statements of codified knowledge; to test or scrutinise scientific statements against competing statements; to achieve a variety of cognitive and sociocultural ends; or to establish coherence between humans, statements and technical devices.

e) The goal of acquiring knowledge is characterised commonly as part of complexes of goals, including variously

- solving problems
- identifying regularities in Nature, often expressed as laws
- identifying the causes of phenomena
- control of Nature, arising from the ability to predict, explain and manipulate
- formulating theories, as descriptions or explanations of phenomena
- as a means of acquiring economic, social, political, military or other power.

f) The history of the western European scientific tradition can be characterised partly by continuity of purposes, particularly gaining reliable knowledge of the cosmos, and partly by changes in purpose, such as changes in notions of laws and theories.

g) The purpose of science is characterised sometimes as its capacity to be useful to individuals, community groups, cognitive science disciplines, industry or governments and nation states.

h) The very utility of science means that most contemporary science serves multiple goals, some of which may conflict with each other, and with traditional notions of science as truth- or knowledge-seeking.

i) The conflict of goals means that the general public frequently finds it difficult to access scientific knowledge and decision making; this has significant implications for the roles of science, scientists and citizens in pluralistic democracies.
II. Implications for a school science that is grounded in the metascientific literature.

School science should articulate a rich notion of scientific purpose, that is more robust than a narrow cognitive goal of learning: it should develop an appreciation of how science knowledge arises from characteristic purposes, such as developing naturalistic explanations that meet the criteria of agreed scientific belief systems. This provides a coherent rather than anecdotal understanding of natural phenomena and scientific explanations of them. Thus a science education would enable students to develop an ability to critique alternative claims to knowledge, and to justify scientific beliefs.

We have noted in earlier chapters that the school science curriculum traditionally characterises science as knowledge and activity, an essentially internalist characterisation that is incomplete and strongly contested in the literature. (The companion chapters on knowledge and activity also argue that the literature characterises scientific knowledge and activity as more varied and complex than many views of science address). The present chapter extends this critique, by arguing that because purpose is an essential dimension of characterisation in the literature, school science should address scientific purposes if it claims to be grounded in the literature of its field. The knowledge and other outcomes of science arise because of complex, characteristic purposes and aims. An incomplete characterisation makes it improbable that citizens could develop a general appreciation of how and why science works, as they increasingly require. To fail to understand that simple, cognitive goals do not account for a great deal of scientific activity, nor account for differences in the views of scientists working towards different ends, is to limit a rationale for the study of science, and reduces the justification of scientific belief. It makes more difficult an appreciation of strengths and limitations of science in comparison with other human endeavours. That is, tensions between different views in society are unlikely to be understood without a robust understanding of scientific purposes. Examples from the present chapter include tensions between the institutional authority arising from purely cognitive goals of science, the needs and goals of individual citizens,
and the ideological and power goals of science, industry, government and community groups. Many of these tensions arise from a tension between the remarkable successes of science in achieving certain goals on the one hand, and changes in goals that are not understood widely; shared goals with industries and governments exist in both categories. It is clear that such issues cannot be understood by glib overviews or mere labels; instead they will require each issue to be analysed, and preferably by more than one approach to analysis, as argued by Martin and Richards (1995).

Claims such as these presume particular views about the role of a school science education in a pluralist democracy, such as exists in Australia, the UK, most western European countries, the USA, Canada and so forth. At the core of this issue is an assumption that the goals or purposes of curriculum areas, in this case science, align more or less with the goals or purposes that a society adopts for its school curriculum. Popper in his *The Open Society and Its Enemies* is an example where science is characterised as contributing positively to a pluralistic, democratic, open society.

These claims apply both to the general science curriculum, and to alternative structures to such a curriculum intended to cater for students possibly intending a career in science. We have seen that citizens require a robust understanding of scientific purpose. Scientists also require this understanding: first, they are also citizens, and second, the example of the napalm research discussed in Appendix B.3 raises significant questions about personal and scientific ethics at least. Now, while it is true that science is partly characterised by attitudes and values as components of a belief system, there are different views about the existence and nature of scientific ethics. Thus we are unlikely to gain agreement from all curriculum stakeholders that scientists should do no research for military goals such as producing napalm. However, we are more likely to secure agreement for conclusions such as by Edwards (op. cit.), that science and technology create possibilities and pressures for meeting social ends, notably industrial, military and commercial purposes. The notion *possibilities* implies the ability to discern the

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2 See Appendix B.2.
implications of goals and complex situations, and pressures implies the ability to construct robust arguments and goals.

Also, science education is measured increasingly by its ability to serve utilitarian purposes, such as the economic well-being of society, through its role as providing exposure to and training in science. Education policy in Australia and other western democracies from the mid-1980s experienced a shift in the influence of curriculum stakeholders resulting in increased pressure on the school curriculum to meet national needs, especially economic goals (McKinnon 1991; Sharpe 1991). That is, there is increasing pressure on the goals of the school curriculum to match broad national policy goals, particularly the goals of science, mathematics and technology in the curriculum. This corresponds with the increasingly utilitarian goals set for science and technology by government policy.

Specific recommendations corresponding to the summary of findings in part I above:

a) The curriculum, at system and class level, should make explicit the often implicit purposes or goals of science. This should include:
   • making clear the purpose of experimental activities in class:
   • making clear the intentions of historical and current scientists; and
   • examining scientific debates and controversies for the research goals and other goals.

b) Students should appreciate the ways in which the science community seeks to generate knowledge with as high a degree of certainty as possible, and why we no longer view this knowledge as certain and immutable Truth. This should include students understanding:
   • that in the histories of science, religions and other social movements knowledge claims were regarded by their believers to be absolute truths;
   • examples of accepted scientific knowledge being supplanted by different understandings, and the grounds for making such claims; and
   • ways in which scientists seek to increase the certainty of their results.
c) Students should appreciate the central insights of the ways in which different scholars seek this certainty: by conforming to observations; by constructing knowledge mentally; and by socially and psychologically seeking to know an external reality. For example, students should become familiar with:

- a variety of techniques by which scientists make and refine observations;
- examples in which different scientists have made, and are making, different conclusions from the same data, or collect different data according to different goals; and
- examples in which our view of the cosmos has changed when the goals of scientific activity have changed.

d) Students should be familiar with other goals related to the development of knowledge: to generate statements; to test competing statements; to achieve other ends; and to make coherent links between actants. For example, students should become familiar with:

- the language of science;
- examples of scientists and others testing competing scientific claims;
- examples showing differences and similarities of goals of scientists and others; and
- how the links between scientists (and others), statements and technical devices are used to make meaning.

e) Students should become familiar with sub-sets of goals that contribute to the goal of developing reliable knowledge, such as solving problems, identifying regularities, identifying causes, controlling Nature (partly expressed by the goals of predicting, explaining and manipulating), constructing theories, and as a means of acquiring power. For example, students should become familiar with:

- the orientation of much scientific activity to solving problems, and the sorts of problems that scientists seek to solve;
examples of problems that scientists do not set out to solve, problems in which the role of science is contentious, and problems that science has yet to solve;

the ways in which regularities are identified, confirmed or disputed, and expressed as laws;

accepted causal explanations of phenomena, and some common notions of cause;

the nature of predictions and explanations, and how experiments are designed to produce them;

the notion of manipulating and controlling Nature;

some commonly used justifications for and critiques of the goal of controlling Nature;

the nature and examples of scientific theories; and

the ways in which scientific research contributes to other goals, notably for economic, social, political and military goals.

Students should appreciate that the history of Western science is partly characterised by goals. For example, students should appreciate that:

some goals, such as developing reliable knowledge, have been enduring in the history of science although their sub-goals, concerning the means, have changed; and

some goals have risen and fallen from favour in the history of science, like developing naturalistic explanations, mastering Nature, and justifying and repudiating the role of God in causing phenomena.

Students should appreciate that the purpose of science is often given as its usefulness. For example, students should appreciate that scientific activity is carried out to serve the purposes of

individuals, both for enrichment, as in fulfilment, curiosity and personal satisfaction, and for empowerment, as in the ability to make informed decisions;
• community groups, who are able to effect changes to communities and others through being informed and skilled;
• cognitive science disciplines, being the organisations of professional scientists that generate the majority of scientific knowledge;
• industry, which increasingly relies on scientific activity to solve problems and facilitate the development of new technologies; and
• governments and nation states, who use scientific knowledge and skills to inform policy, ensure security, and, with industry, are the largest users and supporters of professional scientific activity.

h) Students should appreciate that science, especially because it is useful to so many groups in society, serves multiple goals that may well conflict with each other, and with the goals of traditional, internalist notions of science. For example, students should have opportunities to:
• contrast and evaluate the goals that lead to conflicting claims in the name of science; and
• contrast and evaluate the goals given in traditional characterisations of science, and in studies of science in practice.

i) Students should appreciate the difficulties that citizens, including scientists acting outside the expertise of their professional specialism, have in accessing and interpreting scientific information when community or citizen groups have different goals to those of the science community. For example, students should have opportunities to analyse case studies of citizen action, including action by individual or small groups of scientists:
• against the scientific work of scientists in government or industry bodies;
• to access and interpret scientific information;
• to develop their own scientific knowledge and have it accepted as credible; and
• to stimulate research for a particular purpose, that is subsequently pursued by the relevant professional field, government instrumentality or industry.
In summary, there is a need for school science to address scientific purpose, both as it applies internally to knowledge, and externally to science in society. The rationale for this claim arises both from a comprehensive characterisation of science itself - that is, a robust rather than merely technical understanding of science - and from arguments for the scientific literacy of citizens.
Chapter 9

STRUCTURE

Structure, as in an arrangement of constituent parts, is a necessary, but not sufficient, dimension of science.

Introduction

This chapter comprises an argument that structure is a necessary, but not sufficient, dimension of science. Structure is defined generally, as an arrangement of constituent parts:

(1) mode of building, construction, or organisation; arrangement of parts, elements or constituents;
(2) something built or constructed; a building, bridge, dam, framework, etc.;
(3) a complex system considered from the point of view of the whole rather than of any single part: the structure of modern science;
(4) anything composed of parts arranged together in some way; an organisation. (The Macquarie Dictionary).

That is, the notion of structure is not specific about what is being structured, but instead is a notion of mode, arrangement, construction, complexity, system, composition or organisation. Thus whether the topic of discussion is cognitive structures, organisational structures or language structures, we recognise - characterise - these structures as scientific because they are assembled, arranged, or structured, in ways that are characteristic of science.

Structure is a necessary dimension of science in that it categorises essential meanings of characterisations in the metascientific literature, and that the meanings of the other proposed dimensions will not substitute for its omission. It is not a sufficient dimension of science in that it does not completely characterise science. Where science is characterised by structure it is usually characterised in combination with one or more other dimensions of science: knowledge, purpose, context, activity and belief system. These other dimensions are used in explicating scientific structure, and scientific structure
is used in explicating the other dimensions. The notion of structure pertinent to characterising science varies between different metascientific accounts. The present chapter will make selective use of these accounts only, to suit its purpose. In so doing it will attempt to strike a balance between including sufficient detail to construct the argument and not repeating the detail of general accounts already familiar to the reader acquainted with the literature.

The argument in this chapter is made in four parts:

1) evidence from the analysis of the summary statements;
2) evidence from argument in the metascientific literature;
3) the relationships between the dimension of structure and the other dimensions;
4) conclusions for theorising about the science curriculum.
1. Evidence from the summary statements

The collection of classes (in Table A.7) and text units from the differentiae (column three of Table A.9, headed *Structural*), collectively indicate that science is characterised partly by order, relation, structure, syntax or system. As with the other dimensions, this category of characterisation was constructed from a semantic analysis of many metascientific sources. Thus it includes a wider range of viewpoints than do many individual accounts in the literature.

Now, it could be argued that this is a false distinction: that on the one hand structure is a characteristic of scientific knowledge, and not science itself, and therefore should therefore be included as a descriptor of scientific knowledge; and on the other hand the organisational structure of science is part of the context of science, and should be included there rather than separately. The present thesis argues the contrary position based on the semantic analysis of the summary statements and the categories of meanings: that characterisations of science are argued partly in terms of structure, and that having drawn attention to the structured character of science one cannot make a clear distinction in every case between cognitive and organisational structures. A reasonable analysis of both the knowledge and context of science will address both intellectual and organisational structures; as with the other dimensions proposed in this thesis, structure is not an independent entity, but a dimension, focus or category of meaning used to characterise science. Thus in one sense it would not matter where the present thesis addresses structure, but in another sense to subsume structure under the other dimensions is to fail to make clear how the literature uses the notion of structure. To emphasise a point made elsewhere, the six proposed categories or dimensions of characteristics of science are not intended to be discrete categories; quite the opposite, they are intended to be considered as a notional set, with overlaps between them. However, to omit one category fails to identify that category of meaning.
Some terms interpreted here as characterising structure can be interpreted otherwise: for example, *scientific* law can be interpreted as an expression of reality, or *belief system* as a psychological entity, or *theory* as a given of scientific knowledge. However, this interpretation misses a fundamental insight of language used in metascientific discussion, as given here in the summary statements: that laws and theories, among other things, are *structures*, devised and used by scientists for particular ends. Thus science is characterised in the summary statements not just by knowledge, or processes, and so forth, but with terms such as *body* of knowledge, or *set* of processes, which indicate some notion of structure, composition and cohesion, and not randomness or happenstance in their co-existence:

The term 'science' is usually assumed to have a very precise and well-defined meaning. But it can in fact be used in a variety of ways to indicate:

(a) a *set* of procedures …
(b) a *set* of conclusions or a *body* of knowledge …
(c) an institution or *set* of organisational *arrangements* …
(d) a myth, that is, a *systematic set* of beliefs …
(e) an ideology, that is, an *organised* way of thinking …

(Kenny, in summary statement 14; emphases added)

Thus, the present thesis interprets such wording as characterising science both by knowledge and the *structure* or *body* of its knowledge, by processes and the *set* of such processes, and so forth. It is not only possible but meaningful to interpret the wording both ways, and the analysis of the summary statements in Appendix A.1 was careful to identify and retain all such noun combinations as a means of retaining the multiple possible meanings.

In some summary statements the primary characterisation is a broad notion structure, as in *system*:

[The standard] view [of science] … understands science to be a *systematic* public enterprise … The truth primarily sought is general, *expressed in laws* of nature, which tell us what is always and everywhere the case …

(Scheffler, in summary statement 27; emphases added)

Some summary statements identify particular notions of structure, as in the totality of science being structured as *disciplines* or *fields*:
The natural sciences and engineering are defined as the major fields of science (physical, chemical, biological, earth, engineering and applied, and agriculture) excluding the social sciences and humanities (which are concerned with the extension of knowledge about man [sic], culture and society). (ASTEC report to the Prime Minister of Australia, in summary statement 70; emphases added)

Other summary statements argue structure as the interrelatedness of the component parts giving meaning to the whole, as in a system of sub-systems:

We may conceive 'science' ... as a system essentially relating to the development of knowledge. Component parts of this system are: the producers (researchers), the process of research, the products, the interresses for these products, the reporting sub-system, etc... This system forms itself part of a larger system: science in society. There are many ways of looking at science - at the knowledge-producing and knowledge-distributing industries. (Radnitsky, in summary statement 18)

or as a system of interrelated components:

Belief systems are not simply collections of norms ... They are structures of norms which bear some relationship to each other and vary greatly in the degree to which they are systematic. What is systematic about belief systems is the interrelatedness of the various substantive beliefs. Some systems are more tightly interrelated than others.

At one end of the continuum are belief systems that consist of a few tightly linked general statements from which a fairly large number of specific propositions can be derived. Confronted by a new situation, the believer may refer to the general rule to determine the stance he [sic] should take. Science is an example of such a belief system. The principle of the experiment remains the same regardless of the differences in empirical problems to which it is applied ... the rules of scientific method, being systematic, may be applied to all kinds of data without regard to their location. Thus, a high degree of system is in one sense an aid to diffusion of belief ...

... To the degree that a system of beliefs is highly systematic, social control may be affected on the basis of informal sanctions and may be easily taught and learned. Belief systems with a relatively high degree of system seem to rely on rather general internalised standards to maintain social control - standards such as generalised codes of ethics (science) ... To learn part is to learn all.

... In any kind of belief system that has a high degree of system - a scientific theory, for instance - a change in one proposition requires adjustments in all others. (Borhek & Curtis, in summary statement 75; emphases added)

There are also more idiosyncratic notions of structure, that explicate a particular notion of structure. Thus Needham uses the term structure to characterise science as comprising the meaningful conjunction of otherwise disparate characteristics, in much the same way as the present thesis constructs its argument:
When we say that modern science developed only in Western Europe at the time of Galileo in the late Renaissance, we mean surely that there and then alone there developed the fundamental bases of the structure of the natural sciences as we have them today, namely the application of mathematical hypotheses to Nature, the full understanding and use of the experimental method, the distinction between primary and secondary qualities, the geometrization of space, and the acceptance of the mechanical model of reality. Hypotheses of primitive or medieval type distinguish themselves quite clearly from those of the modern type. Their intrinsic and essential vagueness always made them incapable of proof or disproof, and they were prone to combine in fanciful systems of gnostic correlation. In so far as numerical figures entered into them, numbers were manipulated in forms of "numerology" or number mysticism constructed a priori, not employed as the stuff of qualitative measurements compared a posteriori. (Needham, in summary statement 72; emphases added)

Some statements construct their argument by pointing out explicitly that science is not characterised by mere collections or accumulations of laws, facts or knowledge, for example; that is, it is not just the content of these things, but their structure that makes them characteristically and usefully scientific:

Science is not just a collection of laws, a catalogue of facts, it is a creation of the human mind with its freely invented ideas and concepts. Physical theories try to form a picture of reality and to establish its connections with the wide world of sense impressions. (Einstein and Infield, in summary statement 15; emphases added)

Science is built up with facts, as a house is with stones. But a collection of facts is no more science than a heap of stones is a house. (Poincaré, in summary statement 7; emphases added)

Science is a world picture. It is not a technique; it is not a form of power; it is not even simply an accumulation of knowledge. But it is a highly integrated form of knowledge which makes a world view. (Bronowski, in summary statement 16; emphases added)

In some statements the notion of structure is implicit in, or entailed by, the argument, as in the arrangement of complex sense data according to the structures of logic:

Science is the attempt to make the chaotic diversity of our sense experience correspond to a logically uniform system of thought. (Einstein, in summary statement 10; emphasis added)

Sometimes these structures are called laws and theories, which by their construction represent natural patterns and structures:

Science is a collection of well-attested theories which explain the patterns and regularities and irregularities among carefully studied phenomena. (Harré, in summary statement 40; emphases added)
The present chapter argues that the summary statements, and other passages from the literature, use the term \textit{structure} in more than one way to describe science, as for example:

(a) a cognitive or essentially internalist notion, as in \textit{organised} (or structured) \textit{collections of facts, laws} (7, 15);

(b) as organisation that combines or ignores e/i distinctions, depending on the particular viewpoint, as in \textit{an institution or set of organisational arrangements} (14), or \textit{system} (18), or \textit{enterprise} (19);

(c) or as indistinct in this respect, as in \textit{disciplines} (4).

Each of these refers to some notion of structure: (a) describes a significant characteristic of science knowledge, that its components are arranged as an ordered framework; (b) takes science to be (at least) a social organisation, or corporate entity; (c) may be taken to relate to (a) or (b) or both. For example, the philosopher Stephen Toulmin has argued that disciplines are characterised by concepts, methods and fundamental aims (which the present thesis interprets respectively as knowledge, activity and purpose):

Thus 'the nature of an \textit{intellectual discipline} always involves both its concepts and also the men [sic] who conceived them, both its subject matter or domain and also the over-arching intellectual ambitions uniting the men who work within it' (Toulmin 1972). So a discipline is a continuing historical entity whose continuity is part intellectual and part professional - a discipline being characterised intellectually by a \textit{geneology of problems} and professionally by a \textit{geneology of institutional authority}. (Suppe 1979, pp. 675-6)

Thus for Toulmin at least, scientific knowledge has been structured traditionally as the \textit{disciplines}, but the disciplines also reflect or contribute to the organisation of the scientific enterprise: different departments within university faculties of science, different laboratories, courses of study, journals, professional associations, and so on, reflect the structures of different scientific disciplines. This is discussed in Appendix B.4.3 here and
Appendix B.1. Note that these loose clusters are not discrete categories, but merely indicate something of the scope of structure as used in the literature.

Notions of structure are embedded in the text of a good many of the summary statements, even where the subject of the statement is not *structure* or one of its synonyms. Below are text units indicating various notions of structure from just the first twenty statements. Note that some of the quotes above have been drawn already from the first twenty statements:

- *systematic* study
  (1)
- *general laws*
  (1)
- *systematised* knowledge in general
  (1)
- a particular *branch* of knowledge
  (1)
- *reduce it to order*
  (2)
- *body* of knowledge
  (4)
- a *set* of processes
  (4)
- *domain* of human knowledge and activity
  (5)
- *systematic organisation* of knowledge
  (5)
- Scientists attempt to acquire and *organise* knowledge
  (5)
- *formulation of laws and theories*
  (5)
- *codified in statements* of high generality (*laws and principles*)
  (8)
- expressed in *laws or principles* of greatest generality
  (9)
- *conceptual generalisations*
  (11)
- a way of *ordering* its many facets and checking the validity of this order
  (13)
- a *paradigm*, or conceptual *structure*
  (20)

These examples are given simply to illustrate that even within the first twenty summary statements the general notion of structure applies in various ways. This is sufficient to
base a more thoroughgoing argument for a general interpretation of structure as a category of characterisation; that argument comprises sections 2 and 3, below.
2. Evidence from argument in the metascientific literature

Debates in the metascientific literature address many aspects of structure in science, which again supports a broad interpretation of structure as a dimension of characterisation. Appendix B.4 addresses this scope as follows.

B.4.1 Current metascientific views with respect to structure

Various metascientific views differ in the way they interpret characteristic scientific structures. These are summarised in Table B.4.1.

B.4.2 The unity of science

It is common for the metascientific and other literatures, including public contexts, to refer to science rather than sciences, which is based on a view that there is some underlying, unitary structure of science. This has been interpreted both as a unity of method and of scientific results such as theories. Some recent, post-positivist accounts of science refer instead to sciences, emphasising the variation of characteristic methods, theoretical and other structures.

B.4.3 The role of structure in characterising a western European scientific tradition

The history of western European science is characterised partly by changes in characteristic structures, including knowledge structures and organisational structures.

B.4.4 Structures of knowledge (cognitive structures)

a) laws
b) theories
c) disciplines
d) other cognitive structures

Science is commonly characterised, although often imprecisely so, by structures of knowledge such as laws, theories and disciplines. Appendix B.4.4 discusses each of
these, and some other, ways in which knowledge is characteristically structured in science.

**B.4.5 Organisational structures**

Science is often characterised by a various organisational structures, such as university faculties and academies.

**B.4.6 Language structures**

Science is also characterised by its particular language structures, such as its vocabulary, grammar and syntax, notably a highly nominalised form and use of passive voice and third person. Some views extend this characterisation to argue that the language is not merely necessary to express the concepts, relationships and precision of science (expressing meaning), but that we can only know what is shaped or structured by language (making meaning).
Structure as a necessary dimension of science

The argument to this point, given in detail in Appendix B.4, establishes structure as a (semantic) category of characterisation in the literature: there are a variety of ways in which structure is used to characterise science. Thus science is not characterised simply by ideas, scientists, resources or language but as structures or arrangements of ideas (laws and theories), people and resources (organisations) or language (technical terms and wordings). However, these examples are not explicit reasons for structure being essential. The argument that structure is a necessary dimension does not rest on these examples, but on the arguments they represent: not only do metascientific arguments typically appeal to notions of structure, but many accounts hold that structural factors actually constitute science. That is, laws and theories do not have the meanings claimed of them without their characteristic structures; scientific organisations cannot be understood, whether in their intellectual contexts as disciplines or in relation to broader social contexts, without reference to their structural characteristics; and the meaning and authority of scientific language cannot be understood without understanding its characteristic structural features. These arguments fail if reference to structure is removed. Also, as with the other categories of characterisation, the literature provides detailed accounts of these structural aspects, and indeed a variety of approaches and, often, disputes over them. To understand both the depth and the variety one must be familiar with at least some of the major positions. To recognise only a single position, when there exists a substantial academic literature of explication and debate, is to fail to understand that there may be plausible alternatives, to miss insights provided by alternatives, and especially to be unable to defend the particular view from the attack of other views. One cannot appreciate the strength of a particular view without appreciating the strength of alternative arguments. It follows that to understand science, one must: first, understand the contribution of structural factors to the nature of science; second,
appreciate that accounts of this contribution differ; and third, appreciate the insights of some other characterisations.
3. The relationships between the dimension of structure and other dimensions

a) Structure and knowledge

The combined use of structure and knowledge in the common expression *body of knowledge* was noted at the beginning of this chapter and section 4.4 above. Given that a separate chapter is dedicated to knowledge we will do no more than acknowledge this relationship here.

b) Structure, knowledge, belief system and purpose

Laws

In section 4.3, above, passing reference was made to beliefs giving rise to different notions of scientific law, but scientific laws, as structures, are a manifestation of both belief system and purpose. In the passage from Loewer, quoted above in section 4.4, argues that laws are *discovered*, when many contemporary accounts would substitute or include *constructed*, but the point here is that Loewer identifies the law as a *primary aim* (or *purpose*) of science, that arises from the *belief* of scientists and philosophers *that our universe is governed by scientific laws*, and around which laws *particular scientific subjects are often organised* (that is, *structured*). Thus Loewer characterises this aspect of science in terms of structure, belief system, and purpose, not in isolation, but in combination.

Scientific laws raise interesting and fundamental questions about characterisations of science, because they demonstrably relate to beliefs about what science actually does, and these beliefs relate in turn to beliefs about the nature of the cosmos. There have been at least three main uses of the term *law*, as used in science. First is the notion of a scientific law as a prescription of the God-given regularities in Nature. Thus some accounts argue that the notion of a scientific law arose in the western European scientific
tradition, and not in other cultures, on the basis of a belief in a law-giving God. For example, Needham (1972), Graham (1973) and Ronan (1982) have all noted that the argument that the belief in a personal, powerful deity, held by the Europeans, but not by the Chinese, predisposed the former to look for lawlike regularities:

In the very interesting paper *Human Law and the Laws of Nature* (1951), Needham suggests that the concept of a divine legislator, absent in China, may have been necessary for the genesis of the idea of 'laws of nature,' and also for Western confidence that the secrets of a cosmos ordered by a rational being will be intelligible to rational beings. We no longer think of the phrase 'laws of nature' as anything but a metaphor, but 'the problem is whether the recognition of such statistical regularities and their mathematical expression could have been reached by any other road than that which Western science actually travelled' (Needham 1969). Here, of course, we are at the crux of the matter. As with most if not all answers to the negative question we can think of alternative routes; and the trouble is not that they are plausible but that we can neither estimate their plausibility nor set limits to their proliferation. (Graham 1973, p. 55)

Graham, continuing, expressed reservations about the significance of the belief or non-belief in a divine legislator, even though in seventeenth- and eighteenth-century science the notion of God the clockmaker is significant in a conception of the cosmos as a mechanism, like a clock. From Needham's research we know that the term *law* was not generally used until after Galileo, and in any event the neo-Confucians used the term *li* for principles, moral, political and natural, which may have been adequate. In any event, there are examples of Chinese discussion of the cosmos in terms of 'workmanship', 'authorship' and so on, despite the underlying cause being conceptualised as an impersonal spirit. The point here is that, for Francis Bacon and his successors, but apparently not in other cultures of the time, there was a strong belief in the regular and precise character of Nature, which could be discovered and expressed in law-like statements:

If there is a personal Creator, the universe is not simply there (as for Aristotle) and has not simply grown (as for the Chinese) but has been designed and constructed, so that the way to understand it is to take it to pieces like a man-made instrument and see how it works. This implies that nature is comprehensible in a special way ... (Graham 1973, p. 56)
Although the assumption of natural regularity has remained central in western European science, this view of law as God-given declined as the new empirical science increasingly provided naturalistic explanations and appealed less to the authority of God as explanations of natural phenomena.

However, the term *law* is still used in two senses, and to many more kinds of statements:

Not till the 17th century, did the modern concept of law become dissociated from its theological and prescriptive connotations. *Law* is itself used ambiguously to refer to both statements and what such statements designate (e.g. *Ohm's Law* refers to a proposition and what the proposition describes, viz. a relation between certain variables).

Many different kinds of statements, or phenomena, are called *laws*. They include constitutive, dispositional, developmental, quasi-teleological, abstract and idealised properties, processes and relations, ranging from observed patterns through experimentally established invariances to the fundamental theoretical principles (or ... axioms) of whole branches of sciences; law-statements may express numerical constants or qualitative attributes, developmental sequences, identities or functional relations, statistical correlations or universal features of types of thing. Though all these entities cannot be subsumed under a unitary analysis there are central unifying strands. (Bhaskar 1983e, pp. 229-239)

Some historical examples of laws given as aims of science are given in Appendix B.3 in the present thesis.

In contemporary HPS, there is general agreement that a law is an *expression of a natural regularity*, as in these definitions given in the glossary of Boyd, Gasper and Trout (1991, p. 776):

*Law*:
A causal or statistical relation between at least two factors, or the statement used to express such a relation. Examples are the ideal gas law, $PV=NkT$, and Newton's second law, $F=ma$. Normally, laws tell us something about counterfactual situations.

*Counterfactuals*:
Types of conditional (if ... then) statements whose antecedents or if-clauses express circumstances that are contrary-to-fact, such as 'If it were raining ...' or 'If it had rained ...'. Scientific laws are said to support counterfactuals.

The classical empiricist account of laws is based on Hume's analysis of causation (Bhaskar 1983e), and the main distinction between accounts of laws is between Humean and non-Humean accounts (Loewer 1995, p. 265). A potted version of the argument is
as follows. Our concern with laws arises because one of the aims of science is to identify
the necessary, law-like sequences of events, from among accidental sequences\(^1\). A
necessary sequence of events is usually taken to imply a necessary connection between
events, but the empiricist John Locke (1632-1704) argued that necessary connections in
Nature were unknowable. David Hume (1711-76) extended this critique by arguing that
there are no empirical grounds even for the assumption of natural necessity. Instead, he
argued that our notion of cause is a psychological habit arising from our experiences of
natural regularities:

Hume contended the idea of necessary connections could not be drawn from our
observations of the external world, but is a projection onto it, derived from our
experience of repeated conjunctions of events. Thus Hume analysed the notion
of necessary connection as empirical invariance plus subjective habit of mind.
(Bhaskar 1983e, p. 230)

Hume’s position entails two assumptions which are critical to understanding the
differences between accounts of laws: epistemologically, all (non-analytic) knowledge
must arise from sense-experience, and ontologically, the objects experienced by our
senses must be invariant patterns of events (events conjoined constantly and
deterministically). Thus the first approach to laws, that of empiricists and positivists,
accepts this notion of cause and its assumptions: it is basically Humean, with various
refinements.

Non-Humean accounts reject one or both of these assumptions. The second group,
the constructivist or neo-Kantian position, follows Immanual Kant (1724-1804). It
rejects Hume’s epistemological assumption, and argues instead that what we see as
natural necessity arises from the a priori principles by which we structure our sense data.
In this view, laws are *constructed*, not discovered; constant conjunctions are necessary
but insufficient. Kant argued that Hume failed to show how laws are necessary: in
principle a finite number of conjunctions can support an infinite number of statements; in
principle any well-established law can be made to appear suspect because of

\(^1\) See the companion chapter on purpose and Appendix B.3.
philosophical difficulties, such as the problems of induction and several paradoxes (see the companion chapter on activity for a discussion of induction); and finally, Hume does not account for changes in the way we construct explanations of phenomena:

Finally, the Humean theory furnishes no rationale for scientific development, whereas scientific accounts appear to be stratified around a reapplied distinction between identified phenomena and their structural explanations. (Bhaskar 1983e, p. 231)

A third group, the version of scientific realism Bhaskar calls transcendent realism, denies both Hume's ontological and epistemological premises. Briefly, Bhaskar points out that invariant patterns of events are rare outside of the closed conditions of experiments. Scientists are causal agents of these experimentally controlled invariant patterns of events. If we identify those invariant patterns of events with laws, we arrive at the absurd conclusion that the experimental activity of scientists changes the laws of Nature. Thus both experiments and applied scientific activity are intelligible only if we recognise that patterns of events and laws are ontologically different. ‘Further, if laws are identified with constant conjunctions, then we must ask what governs phenomena in open systems (where no such conjunctions are available)’ (Bhaskar 1983e, p. 231) The empiricist is faced with there being either no laws, or (as argued by both Mill and Lakatos) that science has yet discovered no laws. For example, we saw in the companion chapter on purpose that John Mill (1806-73) sought both those sequences that were invariable and those that held only in certain circumstances: empirical laws stated patterns that held in limited contexts, whereas basic laws of Nature are absolutely invariant patterns. Basic laws can only be deduced from empirical laws. Thus the position of transcendent realism is that laws (natural regularities or patterns) exist but our knowledge of them is constructed: laws are the tendencies of natural mechanisms that exist without being manifest in particular outcomes.
Theories

As with laws, theories also are more completely characterised by the combination of knowledge, structure, belief system and purpose. Rappoport’s classification (itself a structuring) of theories is an interesting combination of these categories, and Suppe’s thorough summary of it is given to illustrate this characterisation:

A stronger argument can be given against the possibility of there being a general deep structural analysis of theories. In an article which has attracted insufficient attention by philosophers, Anatol Rappoport (1958) presents an interesting taxonomy of theories. The following sorts of theories can be distinguished: (i) theories which are intrinsically mathematical ... and describe a state-transition mechanism (‘equations of motion’); examples include classical and quantum mechanics, quantitative analysis in chemistry, and the general theory of natural selection; (ii) the class of theories like the first except that they contain no state-transition mechanism; examples include most theories of equilibrium, classical thermodynamics, crystallography and classical optics; (iii) stochastic theories, which are mathematical and quantised but the basis for quantising is counting rather than measuring ...; characteristic problems are sampling strategies and statistical validation; paradigm examples include theories in genetics, demography, epidemiology, and ecology; (iv) qualitative theories, which concern themselves with such problems as recognition and meaningful classification ...; the success of the theory depends in large part on whether it so organises our observations as to gain a heuristic and predictive advantage; paradigm examples include qualitative analysis in chemistry, and much of biology, and many portions of the behavioural sciences; (v) taxonomic theories, which, while often falling under other classifications given here, have as their central problems recognition and meaningful classification ...; paradigm examples include kinship systems, classifications of natural languages, and biological classification; (vi) historical theories which are concerned to describe the occurrence of single events, rather than classes of events ...; paradigm examples include the continental-drift hypothesis in geology, migratory theories about the origin of the American Indian, and many anthropological and archaeological theories; (vii) theories in the social sciences which have as their primary emphasis the imparting of an intuitive understanding of social behaviour, institutions, political systems, cultures, and the likely paradigm examples include theories in depth psychology such as Freud’s. That the entities commonly called scientific theories evidence such diversity does lend credence to the suggestion that there will not be any particularly deep or revealing characteristics common to all scientific theories other than what Achinstein incorporates into his analysis. (Suppe 1979, pp. 123-4)

This is the sort of philosophical basis that many recent commentaries draw on when they refer to sciences rather than science: the lack of any uniform structure does not support a uniform characterisation of science. It is consistent with multidimensional
Chapter 9: Structure

characterisations such as the present thesis proposes: not only do structures vary, but characteristic purposes, belief systems and so forth.

Another complex characterisation of theories is the critical approach to theories, found in continental philosophy. It expressly combines structure, belief system, context and purpose:

[T]he 'traditional' concept of scientific theory [was] as an entirely disinterested, value-neutral account of the world, a conception that denies from the beginning any intrinsic connection between scientific knowledge and the practical interests in human life. Like all major Western thinkers from Plato to Hegel, Husserl accepted this traditional conception of theory and so, for all his sensitivity to the crisis of Western science, still acquiesced in the split between knowledge and action that sustained the crisis. According to Horkheimer, the solution was to reject the traditional notion of theory in favour of a new concept of critical theory i.e. of theory as deriving from the fundamental practical interests of human life and hence essentially and intrinsically directed towards the improvement of human existence.

The work of Jürgen Habermas represents a systematic and sustained effort to develop and ground this conception of critical theory. Habermas’s fundamental project is to provide a contemporary counterpart to the classical ideal of building human society on the basis of a body of practical knowledge (i.e. a knowledge of basic human values). (Gutting 1990, p. 129)

This critical approach expressly claims that, contrary to the positivist RV, scientific theories have practical or interested purposes that are sometimes characterised as ideologies.

Structure and context

In section 4.4, above, mention was made of the development of scientific institutions, notably the scientific academies, in early modern Europe. Emerson (1990) characterises this organisation development largely in terms of historical and sociopolitical contexts, but also by changes in purpose, knowledge and activity:

All of these institutions had a profound effect upon the pursuit of science. They gave it prestige, social legitimation, recognition and an important place outside the schools and church but within the state among the complex of institutions promoting secular novelties. Defining new roles, they created for the first time scientific careers and a new if small class of professional scientists who served as their permanent and full time functionaries. Because they were recognised, approved and increasingly successful and useful, they promoted the pursuit of science among the classes for whom approval, success and utility were most important - professional men, gentlemen who had to make their way in the world and those who sought to be regarded as polite and useful members of
society. The academies and societies were all committed to the use of experimental methods which they saw as not only providing men with new knowledge but also as eliminating old errors, superstitions and ignorance ... The academies' attitudes toward knowledge supported and helped to drive the European Enlightenment which they did much to define. Societies everywhere became exemplars of good science not only for their respective kingdom but for the European Republic of Letters. Indeed, this Republic and the cosmopolitan ideals it expressed reflected the institutionalisation of science in these new bodies. Their transactions, memoirs, journals and other published works created a new medium for the exchange of information and speeded the dissemination and criticism of new ideas. Even though many of these institutions were also committed to chauvinistic ends, their publications, research programs, prize competitions and work as state agencies gave a direction to national and international scientific activities which had formerly been lacking in Europe. This can be seen not only in the common European pursuit of problems ... but also in the co-operative undertakings such as the observations of the Transit of Venus in 1761 and 1769.

As the academies pursued their projects, they also tended to make science more clearly a distinctive activity requiring rigorous training and specialised expertise. Their own standards and the work of their professional members had encouraged specialisation and had raised the expected levels of performance so that by 1800 few amateurs and virtuosi were to be found among those making significant contributions to natural knowledge. As servants of their respective states the academies increasingly showed how useful specialised bodies possessing scientific knowledge could be to the governments which chartered or supported them. (Emerson 1990, pp. 972-3)

Thus the primary characterisation in this passage is by structure, in that Emerson is discussing structure: institutions such as the Societies as and other bodies, summarised as the institutionalisation of science. However, this characterisation is made largely in terms of context: prestige, social legitimation, recognition and an important place outside the schools and church but within the state among the complex of institutions, among the classes, and European. Other categories of characterisation are knowledge (scientific knowledge), purpose (gave a direction to national and international scientific activities, and the common European pursuit of problems) and activity (experimental methods, research programs).

The final example is a view that science is a structure characterised partly by rules, especially linguistic rules, but the characterisation draws on all six dimensions:

Hagendijk (1990) has recently criticised a version of constructivism that he attributes to Latour. His criticism is based on a view of science as part of a culturally created way of establishing facts that he believes constructivism undermines. He draws on Anthony Giddens's structuration theory as an alternative to constructivism. Here, science is considered to be generated by
rules (especially linguistic rules). Hagendijk, like Giddens, fails to clearly locate rules and cultural conceptions in time and space. This is a critical problem because rules and resources are conceptualised in this theory to be the basic dimension of social structure (see item 4 below). The basic theory can be summarised as follows:

1. Social structures are simultaneously produced and changed by humans, and used as resources; structural properties are the medium and outcome of the practices they recursively organise.

2. Structure is a virtual order of rules and resources; the observable patterns of social interaction are conceptualised as systems.

3. Human agents are assumed to be knowledgeable.

4. The modalities of structuration are rules (normative and interpretive) and resources (political-authoritative, economic-allocative).

Science as an institutional order is theorised to be dependent for its reproduction on configurations of various types of rules and resources. Modern science, then, is supposed to have emerged out of the confluence of material, literary and social technologies (following Shapin and Schaffer 1985). Experimental science is viewed as a new ‘form of life’ with material, cognitive, and moral aspects. The dynamics of boundary maintenance and collaboration are conceived in terms of discourse coalitions and discourse structuration. And national subfields of science are supposed to be created out of the intertwining of cognitive and social arrangements. (Restivo 1995, p. 108)

The present thesis interprets this passage as characterising science using all six dimensions: structure (social structures, structuration, structure is a virtual order of rules and resources, systems and institutional order); activity (generated, produced and changed ... and used, recursively organise, experimental science, and dynamics); knowledge (conceptions, knowledgeable and cognitive); context (cultural, social, humans, resources (political-authoritative, economic-allocative), and national subfields); belief system (rules (normative and interpretive), and moral aspects); and purpose (implicit in, for example, used as resources, and emerged out of the confluence ...).
4. Conclusions for theorising about the science curriculum

This section extends the argument, given above, that scientific structure is an integral part of metascientific characterisations of science, to claim also that it should form part of school science. This argument is based on several premises. First, the preceding argument in this chapter has shown that structure is a necessary but not sufficient dimension of science in the metascientific literature. Secondly, the scope of scientific structure is broader than many individual characterisations of science address: to understand science it is necessary to understand, firstly, that, whichever characteristic we are concerned with derives its scientific significance in part from its particular arrangement or construction. The present chapter sought to show in some detail how this applies particularly to arrangements of knowledge, organisations and language. Thirdly, these structures shape science and different perceptions of it; this also has to be appreciated to make a more complete characterisation of science. Fourthly, the traditional academic school science curriculum is overwhelmingly concerned with science knowledge content and certain activities, as set out particularly in the companion chapters on knowledge and activity; this characterisation of science is both incomplete and strongly contested in the literature. Part 4 of the companion chapter on context rejects such incomplete characterisations for the science education of both the citizen and the science-trained professional, as limiting the understanding and justification of science. This section summarises the discussion in Appendix B.4, and highlights its significance for the curriculum.

As mentioned already, the present, post-positivist understanding of science as given in the metascientific literature is that there is no longer a single received view. Indeed, the unity of science that is usually implicit in such a normative account is challenged by post-positivist accounts, and it may be more instructive to consider the term *sciences* rather than *science*. The current (complex) consensus is that there is a
variety of views, and these views provide different accounts of structure: they may vary in their accounts of particular structures, as in traditional versus critical perspectives of scientific theories, and, more strikingly, explicate structures of different entities. For example, we have discussed in this chapter of science Machlup's historical treatment of knowledge structures, Rappoport's summary of theory structures, scientific organisations as given in Redner, and Cozzens and Woodhouse, and language structures as analysed by Martin and Halliday. Now, it is clear that each of these topics is different, but to argue that we have lumped together dissimilar entities, like apples and oranges, is to miss the point: each of these was characterised by particular arrangements or structures, and it is this appeal to structure that we have identified as a significant - indeed, essential - category of characterisation. This points to a general need to provide a richer notion of structure in school science: clearly there is a need for students to become familiar with at least some of these structures, which are summarised here.

I. Findings about the nature of science from the review of the metascientific literature.

There is a range of currently accepted views of science, which characterise science by various notions of structure as given in contemporary philosophical, sociological, historical and linguistic analysis. Examples given in this chapter can be summarised as:

*There is a tradition of referring to science, that may be less informative than referring to sciences*

a) There is a strong tradition in the literature, and in general use, or referring to *science*; this emphasises similarities, and is reinforced by the notion of unity of science.

b) There is a tendency in post-positivist metascientific literature to examine actual, rather than idealised or normative, characteristics of science; this concerns
differences as well as similarities, and therefore speaks of sciences rather than science. This is most evident where analyses have turned their attention from physics as the paradigm of science, to biology, chemistry and other fields.

c) The present thesis uses the term science, partly because of the common usage, and partly because it concerns the school subject called science. However, in doing so, it recognises that many recent analyses now refer to sciences, and that this term serves to alert us to the diversity of structures, belief systems, activities, purposes, contexts and knowledges that can be masked by the generic term science.

*Scientific knowledge is traditionally structured as disciplines, such as physics and geology.*

d) Science disciplines as currently recognised are in many cases historically recent constructions, and historical analysis shows that science knowledge has been arranged in a variety of ways.

e) The twentieth century has seen considerable pressure on disciplines as cognitive structures, with new fields emerging and existing disciplines merging, such as geophysics.

f) Disciplines can also be characterised as organisational structures, and much contemporary analysis argues that the social and political organisation of science better explains the nature of post-war disciplines than do purely cognitive issues.

g) There are also other attempts to provide a cognitive basis for structuring science, as in Shapere’s notion of scientific domains, which are different from conceptions of disciplines or fields.

h) The Scientific Revolution is often characterised by changes in both cognitive and organisational structures: new fields or disciplines emerged, theories were structured differently (notably using mathematical structures), and scientific organisations emerged.
Other notions of cognitive structure characteristic of science are laws, theories and hypotheses; different metascientific approaches give different views of their structures and significance.

i) Laws are taken usually as statements of regularity or pattern in Nature, specifically the relation between at least two factors: empiricism holds that they are straightforward statements of phenomena, and therefore laws are discovered; constructivism holds that we can only know as a result of the mind (accounting for changes in laws in the light of new evidence), hence laws are constructed; scientific realism (in the account discussed here) holds that laws are statements of natural (real) mechanisms, knowledge of which is constructed using experimental manipulations.

j) Theories are taken usually as systematic accounts, such as descriptions or explanations, of a subject; in science they account for observational (empirical) data, but a strong (but not universal) current view is that they influence observations. Despite their obviously structured character and earlier understandings of theory, no universal structure of theories has been determined. Despite philosophical objections to the imprecision of the notion paradigm, a scientific paradigm as a general theoretical context or as a disciplinary matrix is a structural characteristic that is widely understood in both scientific and lay circles.

k) Hypotheses are taken usually as tentative expressions of theories that require further evidence and testing.

l) The view that theory influences observation (the theory-laden-ness of observations) rejects the popular characterisation of science as an objective, value-free enterprise.
m) The rejection of science as objective has been extended to the argument that theories, not being neutral accounts of Nature, are directed towards improving human existence.

Science is also characterised by organisational structures: disciplines as organisations, university faculties and departments, scientific bodies and academies, and the general organisational character of science in relation to other organisations in society, such as government, industry and citizen organisations.

n) Cognitive structures account for little of science as an organisational structure, and thus provide little understanding of the development and workings of science in society.

Science is identified and constructed also by characteristic structures of language.

o) Scientific language has complex and characteristic structures; the weak interpretation is that these structures are the means by which we express the complexities of scientific knowledge; the strong interpretation is that these structures are the means by which we make these complex understandings.

Structure is a necessary category of meaning in characterisations of science, and is used typical in combination with other dimensions (categories of characterisation).

p) The meanings of laws, theories and scientific language depend partly but essentially on their characteristic structures, as do the rationale and effectiveness of scientific organisations; these fail if we do not account for their structure or composition.
II. Implications for a school science that reflects the metascientific literature.

School science should present a robust notion of scientific structure, in such a way as to provide a coherent rather than anecdotal understanding.

(i) School science needs to address not just the existence of disciplines, laws and theories but an understanding of their status and meaning. The notion of natural regularity or pattern embodied in laws - and indeed the underlying belief in such regularity - is fundamental to the western European tradition of science, yet is poorly acknowledged in public understandings of science (Wynne 1995). A similar argument applies to theories, but more strongly. Theories are explanatory structures, and the special sense in which the scientific community understands scientific explanations to be tentative is poorly understood by the wider community (and sometimes in public controversies by scientists also; see Martin & Richards 1995). The present thesis argues that the appropriate response is not to argue that the public simply 'misunderstand' science (Wynne 1995) or to reject tentativeness: the view of science as absolute truths is long discredited. Rather, the response should be to understand how theories and laws in science are constructed, and how they derive their meaning from particular belief systems, activities, contextual issues, and so forth.

(ii) Similarly with organisational structures: an understanding only of cognitive structures does not provide an understanding of how science works as an institution and in relation to other interests in society. The present thesis argues, again, that the appropriate response is not to reject or ignore this characteristic; the more than thirty years of STS and other research, such as given in Jasanoff et al (1995) and elsewhere, makes a compelling argument for an understanding
based on a more robust characterisation of science, such as the present thesis proposes.

(iii) Likewise, the linguistic structures of science need to be understood, not just because it is their characteristic structures that give them their meaning, but because they present special requirements for students of science. Halliday and Martin (1993) argue in detail that scientific language deters students from learning science: it alienates them and, we might add, alienates non-science-trained adults. They provide compelling evidence that science is understood more easily by addressing directly the linguistic structures of scientific language. Moreover, addressing the scientific language is a means of coming to understand other scientific structures, such as theories, that are constructed in scientific discourse.

Some recommendations corresponding to the summary of findings in part I above:

a) Whether or not school Science retains the name Science, or changes its designation to The Sciences or some other title, it should make clear both some features believed to apply widely, such as patterns of reasoning, assumptions and experimental design, and other features believed to apply more in some sciences than in others. This should include developing an appreciation of:

- patterns of reasoning used widely in the sciences, such as induction and deduction;
- basic factors in experimental design, such as controls, variables, placebos, and so forth;
- the influence of different experimental designs on knowledge outcomes;
• language elements that tend to characterise science generally, such as nominalisation, jargon\(^2\) and passive voice;
• language elements that characterise different sciences, particularly technical vocabularies; and
• non-structural dimensions that are relative to the unity or otherwise of science, such as assumptions (belief systems), purposes, activities and contexts.

b), c) Students should develop an appreciation of both idealised, or normative, characterisations of science, and of descriptive characterisations of science as practised. The former are useful because they are unencumbered by the complexities of real life, and hence typically more straightforward, and because idealised accounts provide the norms to which the scientific communities aspire and by which they are judged. The latter are useful because they bring understanding of science in practice, and hence understandings of why certain tasks are studied and not others, of how scientific disputes arise and are dealt with, of how scientists actually work and communicate, and so forth. This will lead easily into studies of the sciences. This could be achieved using the examples above.

d) Students should develop an appreciation of:
• the various current science disciplines; and
• the history and historical contingency of science disciplines and knowledge structures.

e) Students should develop an appreciation of current changes in science disciplines, both the emergence of new disciplines and the merging of existing

\(^2\) The term \textit{jargon} is used here in its technical sense meaning technical terms that partly characterise a discourse, not in the pejorative sense meaning cluttered and obfuscatory language. Thus \textit{jargon} includes the technical terms that characterise science.
disciplines. Not only is this useful knowledge to have in a science education, but it is motivating. It has the currency and immediacy that for many school students signals relevance, the interests in emerging disciplines reflect current interests in the community such as environmental management, the chemistries of polymers, drugs, fuels and biological processes, advances in surgery, reproductive technologies and so forth, micro-electronics and communications and information technologies, and space travel, to name some common examples. This is not to say that long-standing disciplines are of little use in the school curriculum, because many concepts fundamental to science education arose in those disciplines, and a historical approach is a useful way of developing greater understanding of them (Matthews 1994). However, the school Science curriculum is typically based on traditional notions of the physics, chemistry and biology disciplines: typically without their historical insights, as Matthews argues, and just as typically without even recognising the immense amount of work being done now in recent and emerging disciplines.

f) Students should develop an appreciation of the organisational characteristics of science disciplines, including that their post-war characteristics have arisen not just because of their cognitive structures, but also their socio-political structures.

g) Where students are making comparative studies of disciplines, they should be aware that there are other cognitive bases for structuring science knowledge besides disciplines, such as domains (Shapere 1979).

h) Students should develop an understanding that the Scientific Revolution is characterised as a period of great and significant change in part because of changes in both cognitive and organisational structures: new fields or disciplines emerged, theories were structured differently (notably using mathematical structures), and scientific organisations emerged.
i) Students should develop a knowledge of some basic current and historical scientific laws, and an appreciation of the nature of laws:

- that laws are statements of natural regularities or patterns;
- that laws were traditionally interpreted as being discoveries and statements of truths; and
- that laws are interpreted more recently by some as constructions and statements of our best experimental understanding of natural regularities.

j) Students should develop a knowledge of some basic current and historical scientific theories, and an appreciation of the nature of theories:

- that theories are usually interpreted as descriptions or explanations;
- that theories were traditionally interpreted as arising from observations, where observations are independent of theories;
- that theories are interpreted more recently as influencing observations; and
- that theories arise and are meaningful within paradigms, and typically change with changes in paradigms.

k) Students should develop a knowledge of some current and historical hypotheses, and an appreciation of the nature of hypotheses:

- that hypotheses are interpreted usually as tentative expressions of theories that require further evidence and testing.

Students should have experience at devising their own hypotheses, and at devising tests for their own and others' hypotheses.

l) Students should develop an appreciation of the role of theory in observation, together with the RV notion of objectivity, and the goal or purpose of being as objective as possible. (See companion chapters on purpose and activity.) For example, students should gain an appreciation of:
• the role of the brain in mediating sensory inputs (observations), as in the effect of optical illusions, and in seeking patterns within unfamiliar sense data;
• notions of objectivity, subjectivity, evidence, deduction; and
• the criteria used in different contexts to make judgements about these notions.

m) Students should develop an appreciation of the multiple purposes and uses of scientific theories. For example, students should develop an appreciation of:
• different notions of Nature, both in non-western natural philosophies and in the history of western European science; and
• the effect of these beliefs about Nature on the purposes and activities of science.

n) Students should develop an appreciation of the relationships, and their limits, between the cognitive and organisational structures of science. For example, students should develop an appreciation of:
• the cognitive disciplines of science and the bases for their structures;
• organisational structures of science and the bases for their structures; and
• the limitations of cognitive structures in accounting for the organisational structures of science in society.

o) Students should develop an appreciation of the characteristic elements and structures of scientific language. For example, students should develop an appreciation of:
• technical vocabularies and the notion of jargon;
• the highly nominalised structure of scientific language;
• the use of passive voice;
• the structures and purposes of characteristic science genres such as explanations, reports and recounts; and
• the ways in which the characteristic structures and elements of scientific language shape our view of Nature.

p) Students should develop an appreciation that the meanings of scientific theories, laws and language depends in part on their characteristic structures. This appreciation would arise out of the experiences suggested in the paragraphs above.

School science, at least as given in syllabus documents and external examinations, pays relatively little regard to notions of structure, being concerned primarily with the non-structural characteristics of scientific knowledge and certain activities (see Halliday & Martin 1993; Matthews 1994). The present thesis provides both a rationale and a theoretical framework as a means of including structure in a robust characterisation of science in the school curriculum.
Chapter 10

ACTIVITY

Activity, as in process, change or development, is a necessary, but not sufficient, dimension of science.

Introduction

This chapter comprises an argument that activity, defined generally as process, praxis, change or development, is a necessary but not sufficient characteristic or dimension of science. Activity is a necessary dimension of science in that the meanings of characterisation in the metascientific literature are incomplete without it, and it does not reduce to any of the other dimensions. Activity is not a sufficient dimension of science in that it does not completely characterise science. Where science is characterised in the metascientific literature by activity, usually it is characterised also by one or more other dimensions of science: knowledge, purpose, context, structure and belief system. These other dimensions are used in explicating scientific activity, and scientific activity is used in explicating the other dimensions. Scientific activity is not simply any activity, but certain types of activity, and activity characterised by its association with particular knowledge, purposes, contexts, structures and belief systems. We have noted earlier that activity or process is one of the two commonly used dimensions for characterising science, and the metascientific literature is replete with detailed discussion and debate about the nature and significance of the way science works. As indicated in chapter 5, the present chapter, and Appendix B.5, will use representative examples from these accounts to show some of the ways science is characterised in the literature by activity. As with all the companion chapters, it will not attempt to reproduce or even to systematically summarise the literature, these tasks being beyond the scope of this thesis.

The argument in this chapter is made in four parts:
1) evidence from the analysis of the summary statements in Figure A1, from which the six proposed dimensions were constructed;

2) evidence from argument in the metascientific literature, which will present some issues of recurrent interest arising from characterisations of science by activity, and explore some of the subtleties they entail;

3) the relationships between the dimension of activity and the other dimensions;

4) conclusions for use in theorising about the science curriculum.
1 Evidence from the analysis of the summary statements

Activity as a partial characteristic of science is indicated in the summary statements from the metascientific literature collected in Figure A.1

The collection of classes in Table A.4, and text units from the differentiae in Table A.9 (column two, headed Activity), collectively indicate that science is characterised partly by *something being done* or *something happening*, although this is interpreted very differently across the literature. For example, many traditional characterisations of science address experimental activity, but as this chapter will show, experimental activity is interpreted variously and in many characterisations experimental activity is insufficient to account for all activity. The term *process* is familiar in the science and education literature, including science education, but its meaning is narrow and its use is debated. To label the proposed characteristic by that name would be to invite its interpretation as equating or closely resembling existing uses of *process*. For example, Millar and Driver (1987) have identified three different meanings for the term *processes* as used in science and science education:

These we have identified as: the processes scientists use in investigating the natural world, the cognitive processes involved in learning science and the pedagogical processes taking place in classrooms. We suggest that these are essentially different ... (Millar & Driver 1987, p. 39)

The present paper is concerned primarily with the first of these meanings, and, as indicated above, has found that the literature has wider concerns than merely investigative activity; it is concerned with the second and third meanings only as they are implied by the first. On these grounds the term *process* is too narrow a term to label the semantic category of characterisations in the literature. Similarly, *dynamic* is used ambiguously in the business literature. The term *activity* is proposed as an appropriate label for this category of meanings from the metascientific literature: its meaning is sufficiently broad to encompass the broad range of meanings in the summary statements, and it is not identified already with a particular genre of related literature.
The terms in Tables A.4 and A.9 indicate a great range of activities, processes and changes, supporting a broad interpretation of scientific activity. Some authors characterise science by limited types of activities only, though not always the same activities, while others consider a wide range. For some authors, only experimental activities are of interest, while for others they are part of a larger set of activities. All these characterisations are disputed, as argued in summary statements 25-27 (Scheffler). A point of discrepancy also arises within some statements as well as between them. For example, summary statements 4 and 14 specifically address the characteristic of activity (processes and procedures respectively) among other characteristics. They also mention other activities that are not inquiry activities, although they do not label them necessarily as activities. Summary statements 4 and 14 alone also include explaining, studying, organising, educating, accrediting, approving, discrediting, protecting, relating, thinking, maintaining, and perpetuating.

Thus the terms indicating activity do not have clear, distinct, uniformly agreed, single meanings. The meaning for any one term can vary between statements, with some terms being used differently by different authors. Conversely, different terms sometimes appear to be used synonymously and are used almost interchangeably. In many cases the clear and distinct meaning for a term can be inferred only from the context of the surrounding text. The meaning is often imprecisely defined. For example, in summary statements 4 and 14 processes and procedures are interpreted to mean processes or procedures of inquiry, including experimental processes or procedures (although they are not explicitly identified with experiments).

Two points of discrepancy arise from the meanings of text units in different statements. First, different terms, processes and procedures, are used to label essentially the same concept of inquiring activities. Secondly, we see from some other summary statements that there is disagreement as to what inquiry processes are. Statements 78, 120, 95 and 96 (the latter two both edited by Messell) make contradictory claims about scientific method, reflecting a particular debate over the existence and nature of such a method. In statements 81-84 Schuster seeks to dispense with conventional notions of a
scientific method by establishing a more comprehensive framework. Several statements set out a *standard view* of science, which approximates the positivist RV. This view proposed a fairly fixed notion of scientific activity (statements 25, 30, 33, 47). Others promote some of the more open and variable views of scientific activity that post-date the 'standard view' (statements 36, 38, 39, 81-84).

The variety of terms and their uses leads to a collective imprecision of meaning. Thus, despite the considerable precision of argument presented by many of the authors, the field of metascientific literature is not characterised by agreed, clear and precise use of these terms, nor on which terms are significant. The set of terms indicating activity is not suited, therefore, to further analysis into distinct sub-categories, for to do so is likely to require the acceptance of some of the summary statements and the rejection of others. This would defeat the purpose of the present thesis, which is to construct a broadly acceptable framework for understanding the field.

The variation in use is represented or interpreted in the summary statements by both the variation in the terms used, and by the possible (semantic) interpretation of any one term in one or more of three ways:

(a) as processes, methods, activities or change generally (such as activities, clarification of problems, methods, combination of methods ..., developing, search, skill, study, technique); and/or

(b) as processes manifest in the psychology of individuals, or in the behaviour of individuals or the behaviour of groups (such as behaviour, observing, experimenting, describing, classifying, analysing, explain, approving or discrediting scientific conclusions, protecting the interests of the scientific estate, maintain and perpetuate, making plans, the ability to ... relate propositions); and/or

(c) as abstracted logical, psychological or linguistic processes (such as deductions and inferences, classifying, describing, explain, discover, intuition, ordinary perception, memory and understanding).
These three general interpretations are simply general semantic approaches: they are attempts to represent different meanings of activity in science. Quite clearly, many terms will fit more than one of these interpretations. They are not suggested as classes of categorisation: (1) they do not meet the criterion of each term fitting only one category; (2) attempting to represent them as categories or sub-groups of processes would involve a degree of interpretation not suited to the attempt in this paper to ground the analysis in the literature; (3) this collective imprecision implies a lack of uniformity in the interpretation and use of the terms which renders an analysis based on individual terms difficult to justify; (4) some of the general terms in (a) fit in (b) or (c) depending on how they are used; and (5) the present thesis does not seek to establish a finely constructed hierarchy of classification categories. Again, a broad interpretation of the characteristic of activity will avoid such a difficulty.

Examples from just the first twenty summary statements show some of this diverse meaning:

- study
  - based on the deductions and inferences which can be made
- formulated, from reproducible observations and measurements
- skill; proficiency
- extend the range of experience and to reduce it to order
- all exploratory activities
- to come to a better understanding
- developing
- to explain
- a set of processes for observing, experimenting with, describing, classifying and analysing
- traditionally studied
- domain of human knowledge and activity within which scientists seek
- systematic organisation of knowledge
• Scientists attempt to acquire and organise knowledge

• formulation of laws and theories describing natural processes

• explaining

• testing of proposed explanations by means of empirical observation and experimentation

• built

• an activity characterised by the search for understanding

• accessible to experimental tests

• a search for understanding

• experimental test

• attempt to make the chaotic diversity of our sense experience correspond

• activity

• form conceptual generalisations about the many particulars of empirical evidence

• a way of knowing

• a human activity that has evolved

• a way of looking ... and a way of ordering ... and checking

• procedures for verifying or falsifying

• highly technical measures often requiring mastery of mathematics

• educating and accrediting ..., approving or discrediting ..., and ... protecting ...

• appropriate way to relate to reality

• way of thinking ... to maintain and perpetuate ... social domination and subordination

• creation of the human mind with its freely invented ideas

• form a picture of reality and to establish its connections

• observation

• respond to challenge and questions

• the development of knowledge

• the producers (researchers), the process of research ... the reporting sub-system

• the knowledge-producing and knowledge-distributing industries
• a knowledge producing and knowledge improving enterprise
• activity
• predict and control ... and to explain and understand

Many of the terms are used in wider contexts than just the scientific and metascientific literature, and so are open to a wider interpretation than terms that have only technical or jargon use. In these cases the reader may associate particular meanings to them in the present discussion. The examples of process and dynamic have been mentioned above in this context. Some of these subtleties of use will be mentioned in the analysis later in this chapter and in Appendix B.5.

Given the discussion above, a definitive treatment of the characteristic of activity is implausible; it is certainly beyond the scope of this paper. We have noted already a variety of activities named, variation in the terminology used in describing them, and different accounts of particular activities, sometimes in stark contradiction with each other. On these grounds alone, agreement on a single definitive statement would be an improbable outcome. More significantly, the very notion of a definitive explication is at odds with some of the views included in the summary statements. In any event a definitive explication is not necessary to serve the purpose of this chapter, which is to make the case that activity is a necessary but not sufficient characteristic of science. Instead, in establishing that science is partly characterised by some developmental, dynamic or active aspect, the remainder of this chapter and Appendix B.5 will address a range of issues found in the literature which, taken collectively, indicate (a) some of the ways in which such activities are understood, and (b) some of the issues by which this understanding is argued and contested. An account of the nature of science must say something about activity if it is to be adequate but it is not possible to say everything about the nature of that activity.
Debates in the metascientific literature address many aspects of scientific activity, again supporting a broad interpretation of scientific activity. It is clear that the literature draws upon a broader notion of activity than many individual thinkers have proposed. This breadth is interpreted both as a wider range of activities than many individual accounts recognise, and as different interpretations of the same activities. The variations, implications and subtleties of the views in several of these debates are outlined below, but discussed in detail in Appendix B.5.

B.5.1 Activity as observable and non-observable

Science is characterised most obviously by - and indeed is manifest in - observable activities, but it is also characterised by mental or non-observable activities.

B.5.2 Activity as method and methodology

Science is commonly characterised, at least in the metascientific literature, by particular methodologies rather than methods, where methodology is our understanding of the principles and logic that underpin scientific inquiry.

B.5.3 The characterisation of a Western European scientific tradition by activity

Histories of the western European scientific tradition routinely characterise science by activity, both technical and reasoning activities, and both the developments of characteristic methods and methodologies. For example, the development of a tradition of hypothetico-deductivism characterises much of science history (Oldroyd 1989).

B.5.4 The problem of induction

Induction is a long-standing methodological tradition in western European science, and remains a plausible way to build a commonsense view of the world. However, there are severe philosophical flaws with induction, for which there are no clear solutions. Among the responses have been to propose methodologies that do not require induction,
as in falsificationism, and to require only that inductions be probably true given large enough samples.

B.5.5 The characterisation of key metascientific viewpoints by activity

Various metascientific views characterise science by different activities. While all acknowledge empirical activities as central, the views differ in their emphasis and interpretation and in their account of other activities. These views are summarised in Table B.5.1.

B.5.6 The notion of a uniform method of science

Many characterisations of science have traditionally referred to a single, uniform scientific method, but this is rejected in post-positivist accounts of science.

B.5.7 Interpretations of some characteristic scientific activities: experiment, observation, explanation and prediction

Experiment, observation, explanation and prediction are central activities in most views of science. The relationship between theory and experiment, and in particular theory and observation is of particular interest. In many popular and traditional accounts of science, scientific observation (and perhaps experiment) is 'objective', meaning independent of theory and preceding it. However, at least in many examples, post-positivist accounts identify a role of theory as influencing, however implicitly, observations. This is the 'theory-laden-ness' of observation. The recently emerged genre of laboratory studies have shifted from considering only idealised reconstructions of experiments to explicating all activities in laboratories, with the result that scientific knowledge is argued to arise from a much broader range of activities. Part of the theory-laden-ness of observations is the link between observation and language, in which language is interpreted as not merely being the means of representing reality, but also of constructing our knowledge of it.
B.5.8 Mathematical activities in science

Science is characterised partly by mathematical activities, notably the development of graphing and calculus to represent variation, of algebra to represent all existing magnitudes, and in the twentieth century of massive increases in computational power.

B.5.9 Debate over discovery and verification

The positivist RV rejected discovery as a characteristic scientific activity because it was not subject to rational interpretation or reconstruction, and relegating it to psychology and history. Thus there was no account of the formation of hypotheses, only their rational justification. In post-positivist accounts of science this is a distortion of scientific activity, and there are various accounts of the activities by which hypotheses are formed.

B.5.10 Activity as more than method and methodology: internalist and externalist perspectives on scientific activity

Post-positivist accounts characterise science by more than just experimental activities, for several reasons. Experiment is now believed to be less distinct as an activity than once thought. The role of experiment is now characterised as much more complex, and a wider range of activities are now believed, in most accounts, to contribute to the intelligibility of science. For example, the philosopher Roy Bhaskar (1975) has argued that the role of scientists’ work in creating meaning from experiments is not recognised by traditional philosophies of science. Similarly, the sociologist Jerome Ravetz (1971) has argued that the activities of scientists have craft-like characteristics that are critical to the success of science, and again are not represented in traditional characterisations of science. Furthermore, expressions of scientific activity in science policy, such as by governments, may not even argue the differences from traditional views and simply presume a broader scope of scientific activity in planning and measuring the outcomes of science.
Activity as a necessary dimension of science

The argument above and in Appendix B.5 has shown a variety of ways in which the metascientific literature characterises science by activity. As a list it is not an argument that activity is a necessary dimension of science. Rather, it is the arguments, summarised in such a list, that metascientific arguments claim that there are characteristic activities of science and that characterisations would fail without them. Further, the variety of accounts and interpretations means that understanding of scientific activity entails some familiarity with at least some of the major views and their differences. To recognise only a single position, when there exists a substantial academic literature of debate, is to fail to appreciate that there may be plausible alternatives, to miss insights provided by alternatives, and especially to be unable to defend a particular view from the attack of other views. One cannot appreciate the certainty or strength of a particular view without appreciating the strength of alternative arguments. It follows that to understand science, one must: first, understand the contribution of activities to the nature of science; secondly, appreciate that accounts of this contribution differ; and thirdly, appreciate the insights of some alternative characterisations.
3) The relationships between the dimension of activity and the other dimensions

The discussion in Appendix 5, of activity as characterised in the metascientific literature, made occasional and passing references to other dimensions of characterisation. As in each of the companion chapters, this section will provide a few examples of characterisations employing activity in combination with other dimensions.

Activity, belief system and knowledge

There are many examples of the general interaction of activity, knowledge and belief system. Notably, science is commonly characterised by beliefs about the appropriate activities for interacting with the cosmos, that are logically expressed in those very activities and result in knowledge of the cosmos:

... I [have] argued that, as a result of the evolution of scientific thought, there has emerged a broad and coherent picture of the universe and of life in it, a view which, while incomplete and in some aspects open to serious question, is at present the best picture available. In the present section I will argue that this process of unification has not been restricted to the integration of beliefs about the world, but that there has also been a progressive tendency toward unification of those beliefs with the methods employed to attain well-grounded beliefs. That is, I will argue, the methods we consider appropriate for arriving at well-grounded beliefs about the world have come more and more to be shaped by those very beliefs, and have evolved with the evolution of knowledge.

Such a view of the intimate relation between knowledge and the methods of gaining knowledge flies in the face of the traditional sharp bifurcation of the two. For it is, and has long been, commonly assumed that there exists a unique method, the 'scientific' or 'empirical' or 'experimental' method, allegedly discovered or at least first systematically applied in the seventeenth century, which can be formulated wholly independently of, and is wholly unaffected by, the knowledge which is arrived at by its means. It is as though scientific method is a set of abstract and immutable rules, like the rules of chess, independent of the strategies of the game but governing what strategies are possible.

Yet the most strenuous efforts of scientists and philosophers have failed to produce agreement as to precisely what that method is. Indeed, general philosophical theories about science according to which there is an eternal scientific method which, once discovered, needs only to be applied to generate knowledge, but which itself will not alter in the light of that knowledge, have proved either empty or false. (Shapere 1984, p. 178)

Thus the significance of Galileo's and Kepler's mathematical developments is not simply changes in methods or methodologies, but shifts in beliefs as to what the mathematics represents: new ontological and epistemological possibilities. The ontological and epistemological implications are significant in the literature. The precedence of activity
vis-a-vis belief system is not fixed, either. Hacking’s (1983) analysis of the relationship between theory (a structure that if well established is interpreted here as an expression of belief system) or experiment, gave examples of prior theory, of experimental activity prior to an explanatory theory and of concurrent development of the two. Of course, dissemblance of theory into various reasoning activities (as theorising) blurs this distinction, but is not made here because the reduction of all to activity obscures the role of the theory as product.

The following passage is a good example of this interplay and its dissociation from what would be regarded typically as a ‘common-sense’ view of the world. The context of the passage is that Davies (1988) has introduced the notion, arising from quantum physics, that ‘the world of our experience - the universe that we actually perceive - is not the only universe’, that there are ‘countless billions’ of ‘parallel’ universes alongside ours (Davies 1988, pp. 11-12). The concern here is the role of mathematical activity and beliefs about this mathematics activity and the nature of the cosmos:

In the mid-1960s a remarkable mathematical formula was discovered by the physicist John Bell. Any logical theory based on the independent reality of sub-atomic particles which adheres to the well-established principle that faster-than-light signalling is impossible obeys this formula. Quantum theory on the other hand does not. Recent experiments in which pairs of photons (particles of light) are sent simultaneously through two pieces of polarised material set obliquely to one another confirm that Bell’s formula is indeed violated.

These studies show that reality, inasmuch as it has any meaning at all, is not a property of the external world on its own but is intimately bound up with our perceptions of the world - our presence as conscious observers. (Davies 1988, p. 12)

That is, Davies appeals to the interplay between activity (observing and mathematical) and belief system (beliefs about reality) in characterising science.

Criteria for activity, arising from the belief system

On the present analysis, some well-known historical developments in scientific activity are more accurately and usefully identified as associated with changes in the belief system. For example, two influential developments in inquiry activity have concerned expositions of beliefs, criteria or rules (all elements of the belief system) about activities. One is Newton’s four ‘Rules of Reasoning in Philosophy’ in the third edition of the Principia in 1687 (Newton 1713/1934), which constitute criteria relating beliefs about the
cosmos to developing knowledge of it. More widely known are Mill’s Canons, which are not descriptions of activities but principles for conducting inductive inquiry; they are mentioned in Appendix B.2.

Another development frequently noted in the literature is a change in the interpretation of the significance of the mathematical procedures. The Aristotelian and Ptolemaic approaches of the Middle Ages had been interpreted as functional descriptions but not representing reality. This was called *saving the phenomena*, as discussed in Appendix B.2 on belief system. The shift from mediaeval to classical science is usually characterised partly by a shift in beliefs about the significance of mathematical activities, from functional descriptions (instrumentalism) to representing reality. As we have seen, instrumentalism and realism remain current, although competing, views of science today.

The interplay between mathematics and science was strengthened by Rene Descartes, whose Cartesian system was very influential for several generations (Singer 1959, p. 264; Dijksterhuis 1986, p. 408). Descartes made strong ontological claims about the relationship of mathematics to the cosmos, that Nature corresponded fundamentally with numbers (Singer, p. 226) but not in the ways claimed by numerology. The Cartesian belief justified the mathematical activity that is identified down to the present day, which in constructivist interpretations (such as Descartes and Kant) identifies the products of mathematics and science with mental activity.

From Newton’s work the fundamental belief that Nature could be represented mathematically led to a mathematical physics that enabled quantitative and more reliable explanations of Nature. This fundamentally shaped what became known as Classical science: a coherent and plausible synthesis of ontological, epistemological and methodological beliefs, including notions of experimentation, the use of mathematics, and the relation of this mathematics to metaphysical entities. The role of the belief system is examined in Chapter 7 of this thesis.

*Activity and knowledge*

Elements of the interdependence of activity and knowledge have been addressed in the discussion in Appendix B.5 on experiment and theory, to the extent that theories are
constructs of knowledge. Historically, the success of the new experimental techniques contributed to the decline of the older belief systems, such as Aristotelian and magical beliefs, and the activities that characterised them. Further, the sheer scope of activity brought about the possibility of a far more integrated and comprehensive understanding of the cosmos. The mathematical techniques that enabled relativity and quantum theories in the twentieth century are clear examples of this in physics; microscopic techniques, including staining and electron and ion microscopy techniques, are examples in biology.

**Activity, structure and purpose**

The comparison of deduction, induction and abduction in Appendix B.5.9 is a straightforward example of the interrelationship between activity and structure. These activities derive their distinctiveness from their characteristic structures: alterations to these structures either create errors, as in erroneous deductions, or convert them to other syllogisms with different meanings. Further, each of these activities has a different purpose that arises from its characteristic structure, as given by the passage quoted in Appendix B.5.9, from Hookway (1992a).
4) Conclusions for use in theorising about the science curriculum

This section extends the argument, given above, that activity is integral to characterisations of science in the literature, to claim also that it should form part of school science. First, the present chapter has argued that activity is a necessary, but not sufficient, characteristic of science in the literature. Secondly, the scope of scientific activity is broader than many individual characterisations address, in particular traditional internalist characterisations common in school curricula. Thus to understand science, it is necessary to have a robust understanding of scientific activity, which includes an appreciation that there is a variety of views of science that provide a variety of insights.

The introduction to the present thesis referred to Millar and Driver (1987) as challenging the traditional characterisation of science by/as knowledge and/or processes. Specifically, Millar and Driver claim the authority of ‘current philosophy of science’:

[T]here is no empirical evidence to support the view that a clearly describable method of science, consisting of a set of identifiable ‘processes’, exists. We argue that the commonly listed processes are aspects of our general cognitive functioning from infancy and that science can lay no special claim to them. (Millar & Driver 1987, p. 36)

And again on page 45:

Firstly we suggest that to characterise the contribution that science makes to the curriculum in terms of teaching its method is a proposition which is based on the shakiest of foundations. There is little support for the view that an algorithm for gaining and validating scientific knowledge can be identified and communicated to others. Secondly, we argue that the idea of separate ‘science processes’ as being uniquely characteristic of the way scientists work also fails to stand up to scrutiny; the ‘processes’ which are commonly identified as ‘scientific’ are in fact characteristic of many human endeavours. We will argue in the final section of the paper that it is not the ‘process’ or, indeed, the ‘processes’ which characterise science. It is to the ‘constructs’ and purposes that we must look for the particular characteristics of science, and for a rationale for its curricular position. (Millar & Driver 1987, p.45)

While endorsing the strategy of Millar and Driver in seeking to ground school science more accurately in current metascientific understandings of science, the present thesis

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1 Note that Millar and Driver mention ‘constructs’ and purposes ... for the particular characteristics of science, which the present thesis identifies as structure and purpose, but which Millar and Driver failed to explore.
draws partly different conclusions from its more explicit and systematic analysis of the literature.

First, it is generally agreed by scholars that no clearly describable method of science exists, but it is disingenuous to conflate the notion of a single scientific method, common in school science, popular images of science, and perhaps undergraduate science, with a generalised philosophy of science that has long abandoned such a notion. Further, the position taken in the present thesis is to reject claims to the authority of stylised fields such as the philosophy of science or the sociology of science, or even just science.

Secondly, it is also true that many activities undertaken in science are indeed 'characteristic of many human endeavours', but this misses the point in several respects:

- These activities are characteristic of science in particular when in combination with a belief system, structures, conceptual framework, purpose and context identified with science.
- The converse is not so necessarily: activities of many human endeavours are not characteristic of science. Rhyming, for example, is characteristic of poetry but not of science. It would be misleading to imply that, because activities traditionally thought to be characteristic of science are found elsewhere that they do not characterise science.
- Many activities now in more general use arose in a scientific context. While the notion of controlling variables or predicting, for example, have a wider use than the technical, scientific sense, they were developed and refined in scientific contexts.

Thirdly, detailed semantic analysis of the metascientific literature, as undertaken in the present thesis, indicates very clearly that a much broader conception of activity than the traditionally identified observing, predicting, and so forth, is embedded in explications of science. Broader notions of activity are part of the conceptual resources used in the metascientific literature in such discussions, and ignorance of them will limit and distort an understanding of science and facility with it.
Thus the present thesis supports Millar and Driver, in that the methods usually thought to characterise science are characteristic of sound thinking generally and not science uniquely. However, it also argues that methods do characterise science when in combination with the other five dimensions of characterisation, and that experimental methods are only part of a broader range of activities that characterise science.

I. Summary of findings about the nature of science from the review of the metascientific literature.

*There is a range of views of science activity*

a) Science is characterised by both observable (technical) and non-observable (mental or logical) activities.

b) Scientific methods are understood and rationalised by methodologies.

c) The popular notion of a unitary *scientific method* is contentious, and rejected by recent metascientific scholarship.

d) The western European scientific tradition can be characterised partly by developments of methods and methodologies.

*There is a variety of activities that characterise science.*

e) Variants of hypothetico-deductivism - forming hypotheses and making deductions from them - have been an enduring characterisation of scientific activity in HPS.

f) The formation of hypotheses in science is contentious in the literature: various accounts have characterised it as induction, discovery, conjecture and social negotiation.

g) Induction is a plausible account of making generalisations and hypotheses from empirical data, although philosophy shows that naive versions, at least, are flawed.

h) Discovery is contentious in the metascientific literature, largely because the positivist RV rejected it as a psychological and historical issue that cannot be rationally justified; many accounts in the post-positivist literature seek to redress this imbalance in order to understand knowledge acquisition in science.
i) Accounts of discovery include the psychological (focussing on the fresh conceptualisation) and the sociological (focussing on the scientific status of discovery rather than accounts of mere learning).

j) Some accounts, such as Popper’s falsificationism, allow simple, bold conjecture as a means of generating a hypothesis.

k) Many post-positivist accounts, notably critical accounts in STS, reject rationalisations of forming hypotheses because they tend to be normative rather than describing actual practices; instead they seek to elucidate actual instances of scientists interacting with each other, phenomena and instruments, in actual rather than idealised contexts.

l) Experiment is ‘a designed practical intervention in Nature’ (Bhaskar 1983c, p. 136) in which observations are made in socially contrived, purposeful, controlled and reproducible conditions; experimentation is widely accepted as a characteristic science activity, even in accounts where it is not emphasised.

m) Traditionally, experiments were considered to produce the observational data from which hypotheses and, ultimately, theories were constructed; that is, observations were held to be prior to, or independent of, theory, meaning objective.

n) Post-positivist accounts typically regard observations as influenced by theory, or theory-laden; many accounts interpret observations as being influenced by a Weltanschauungen, or world view, which the present thesis interprets as part of the belief system of the observer; other accounts characterise observations and theories as being determined by language (the linguistic resources of the observer).

o) Another activity that some accounts claim characterises science is explanation; positivists hold that science can only provide descriptions of phenomena, not explanations of them, but this is contentious.

p) Another activity that characterises science is prediction; it is the predictive successes of science that confer on it authority.

q) Mathematical activities have long been associated with science, and increasingly characterise scientific activity; these include the use of algebra, the mathematics of
variation (calculus), and massive increases in computational power that have caused the flourishing of many fields and the growth of completely new fields, such as artificial intelligence, cosmology, sub-atomic physics, and mathematical modelling.

r) Post-positivist accounts of science have been concerned not just to revisit characterisations of experiment, but to clarify the role of non-experimental activities in science; these arise from critiques of experiment and assumptions that the social role of science needs explanation.

s) Extra-experimental characterisations of scientific activity include the craft-like character of scientists’ skills, science as work, and the measurement of activity by outcomes such as economic value and publications output.

II. Implications for a school science that reflects the metascientific literature

School science should present a robust notion of scientific activity, in such a way as to provide a coherent, rather than anecdotal, understanding. We have noted that Millar and Driver distinguish three meanings of the term processes in science education, respectively processes of investigation, learning and pedagogy, and that the present thesis is concerned with the second and third meanings only as they are influenced by the present analysis of the first.

Given the centrally empirical character of science, students should investigate phenomena. However, there should be some caveats on this statement. First, critiques of process-based science education (such as Millar & Driver 1987) question the effectiveness of open-ended inquiry-based learning as the sole, or even the dominant, mode of instruction and learning. Secondly, the present thesis identifies a range of

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2 The traditional characterisation of science as knowledge and/or processes is consistent with the education tradition of categorising objectives as knowledge/skills/attitudes - that we know, we do, and we have particular dispositions towards things. This is to confuse a concept about people (that we know, do, feel) with a concept about science. To have scientific knowledge, for example, is not just to have the currently accepted knowledge of the cosmos, but to have knowledge of science itself - knowledge of skills, of resources, of authorities in the field, etc. But this alone does not address the purposeful nature of science, and other dimensions proposed by the present thesis.
investigative methods, and in particular a rejection of the notion of a single, common, scientific method. Therefore the present thesis advocates that students experience, and be made aware of, a variety of strategies, both in their own investigations, and case studies of actual investigations.

Thirdly, the present thesis also identified a strong theme in post-positivist accounts that experimental activity alone does not account for the generation and use of science knowledge. Therefore, students should also experience, first hand and through case studies, examples of the broader range of activities by which the literature characterises science.

A note about practical work in school Science

One influence of philosophical and sociological views of classroom science featured in the 1950/1960s curriculum projects, was the emphasis on the importance of practical work in science. This came from two sources. First, it came from educational theorists: Armstrong's ideas of heuristic tasks and Dewey's ideas of learning by doing, though both dating from earlier in the century, influenced science curriculum projects in the 1950/1960s in the UK and the USA respectively (Fensham 1992, p. 792). Secondly, it came from the philosophy of science. Schwab, for instance, argued in the BSCS project that science is a process of inquiry, and therefore has implications for the curriculum:

To teach science as inquiry, he suggested that two changes were needed in the role of the laboratory. First, a substantial part of the laboratory work should be made to lead rather than to lag the classroom phase of science teaching. Second, the demonstration function of the laboratory should be subordinated to two other functions, namely, to provide a tangible experience of some of the problems of acquiring data dealt with in science and to provide occasions for an invitation to conduct miniature but exemplary programs of inquiry (Fensham, 1992, p. 792).

A second influence, also from the philosophy of science, was the advocacy of the use of models, as in the PSSC project. A third influence was the so-called process approach in which the processes of science themselves became the things to be learned, the learning objectives, in the curriculum. This led to two outcomes that will be taken up later in this thesis. One was that the processes tended to be treated separately, producing what Fensham (1992, p. 792) called 'atomised components of the investigative methods
scientists employ’. The other was that the processes tended to separate from the content, that is, the knowledge:

Initially ... (processes) had been advocated as essential components of the content of science to complement and to give a dynamic to the otherwise potentially sterile body of facts and conceptual knowledge that was now being seen as appropriate for school learners.

... In the struggle, however, to apportion the new ideas about what the content of school science might be in its traditional place in secondary education, and the pressure for it also to be part of the curriculum of the earlier years, a quite unphilosophical dissection occurred. Stated a little crudely but without much exaggeration, the elementary or primary curriculum got the processes, and the secondary curriculum retained the content of science, which was now much more conceptual and less factual and descriptive (Fensham 1992, p. 792)

Historical, philosophical and sociological influences were much greater by the 1980s, both on the scope and number of ideas, and the creation and implementation of curricula. This is of central interest to this paper.

In Fensham’s view, the philosophical viewpoint has changed chiefly with respect to some revision of the claims made for practical work:

For example, Hodson (1988) has refined Schwab’s earlier work on Science as Enquiry by pointing out differences among the inquiries in science. Each one arises in relation to specific subject matter, and the essence lies in the sorts of concepts, data, and questions that are employed. It is this interweaving of phenomena, concept and process that Millar and Driver (1987) express in their concerns about the predominant place many junior science curricula have given to science processes over science content. Lybeck (1981), in his study of the teaching and learning of the Archimedes principle, has provided a splendid example of the point Hodson is making. Earlier Hodson (1985) used a philosophical basis to identify a number of distinct learnings in science education. If these distinctions are not to be blurred or lost, he argues, each needs a definite ‘space’ in the curriculum so that students recognise it for what it is and have enough practice with it. (Fensham 1992, p. 802)

Suggestions as to how this can be achieved have been made by other writers and in some curriculum materials.

Finally, note that the traditional characterisation of science as knowledge and/or processes is consistent with the education tradition of categorising objectives as knowledge/skills/attitudes - that we know, we do, we have particular dispositions towards things. This is to confuse a concept about people (that we know, do, feel) with a concept about science. To have scientific knowledge, for example, is not just to have the currently accepted knowledge of the cosmos, but to have knowledge of science itself, such as knowledge of skills, resources or authorities in the field. But even this alone does
not address the dimensions of nature of science that are purposeful, are structured, and so forth.

Following are some specific examples in response to the summary in part I, above.

*There is a range of views of science activity*

a) Students should develop an appreciation of, have some experience of, and develop some competence in a variety of observable (technical) and non-observable (mental) activities. Some examples could be:

- Students should be able use a variety of instruments and apparatus used to extend the senses and manipulate the environment. These should include both simple, traditional school laboratory apparatus, and examples of electronic, information and communication technologies.
- Students should have opportunities to develop mental skills, such as comparing, predicting, analysing and evaluating arguments, and making judgements.
- Students should develop metacognitive skills.

b) Students should develop an appreciation of some methodologies, such as induction, hypothetico-deductivism, verificationism and falsificationism. For example:

- Students should have opportunities to evaluate and compare the effects of different methodologies, such as the effects on an investigation of verificationist and falsificationist strategies. Opportunities should include investigations carried out by the students/class, and case studies of actual scientific work.

c) Students should understand that investigative activity in science is not formula-driven and instead proceeds by various methods, although some activities, like observation and prediction, are typical. For example:

- Students should have the opportunity to analyse investigations, both their own and case studies of others, to identify component activities and their purposes.
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d) Students should develop an appreciation of how methods and methodologies partly characterise the western European scientific tradition. For example:

- Students should study and where feasible replicate historical examples of simple experiments in order both to develop their own scientific understandings and to appreciate how these understandings represented historical developments.

There is a variety of activities that characterise science.

e) Students should gain an appreciation of the significance of hypothetico-deductivism in western European science. For example:

- Students should have experiences in forming hypotheses and making deductions from them.

f, j) Students should develop an appreciation of the range of views of generating hypotheses, such as induction, discovery, conjecture and negotiation.

- Students should analyse a variety of examples of hypothesising, both from their own efforts and from case studies of historical and contemporary examples.

g) Students should gain an appreciation of the nature and role of induction, and of some of its flaws.

- Students should analyse a variety of examples of induction, both from their own efforts and from case studies of historical and contemporary examples.

h, i) Students should gain an appreciation of the nature and role of discovery as an activity of knowledge acquisition, and of critiques of discovery.

- Students should analyse a variety of examples of scientific discoveries from case studies of historical and contemporary examples.

k) Students should gain an appreciation of actual examples of scientists hypothesising, and not just idealised examples. For example:

- Students should analyse a variety of examples of actual hypothesising from case studies of historical and contemporary examples.
• Students should have opportunities to compare examples of actual hypothesising with their rational reconstructions.

l) Students should gain an appreciation of the nature and role of experiment in science, including experimental purposes, structures, controls, reproducibility and social contrivance. For example:
• Students should develop skills in designing experiments, controlling variables, replicating, and comparing the results of different experimental designs.
• Students should analyse case studies of historical and contemporary experiments.

m, n) Students should gain an appreciation of the interplay between observation and theory, such as the ideal (once the prescription) of theory-independent observation, and the role of theory and language in observations.
• Students should analyse examples where experimental (observational) data are or have been interpreted in more than one way, and the criteria used to make these judgements.

o) Students should gain an appreciation of the nature and role of explanation in science, and that there are different views of explanation.
• Students should analyse, using more than one account of explanation, examples of explanations given by scientists and others.

p) Students should gain an appreciation of the nature and role of prediction in science.
• Students should develop skills in making predictions and testing them.
• Students should analyse case studies of historical and contemporary predictions.

q) Students should gain an appreciation of the role of mathematics in science, including experience themselves in mathematical activity.
• Students should have opportunities to develop non-mathematical, non-quantitative understandings of science concepts.
• Students should develop an appreciation of the role of mathematics in refining understandings, refining measurements, and in enabling fresh understandings.

• Students should develop mathematical skills and knowledge and have opportunities to apply them in scientific contexts.

r, s) Students should gain an appreciation of the natures and roles of non-experimental activities in science. In particular, students should gain some proficiency in the craft-like character of scientific skills, gain an appreciation of science as work, and the ways in which scientific work is measured.

• Students should develop craft skills of science, such as observation, manipulation, calibration, assembly, fabrication and the care of living organisms; they should develop an appreciation of the role and value of these skills.

• Students should have opportunities to see scientists at work, both in person and through audio-visual or multimedia resources, and where possible to interact with scientists.

• Students could have opportunities to do work-study with scientists.

• Students should develop a familiarity with scientific journals and other examples of scientists’ work, and develop an appreciation of their worth.
Chapter 11

KNOWLEDGE

Knowledge, as in the state of knowing and a body of truths, facts or wisdom, is a necessary, but not sufficient, dimension of science.

Introduction

This chapter comprises an argument that knowledge is a necessary, but not sufficient, dimension of science. Knowledge is defined generally, for example:

[Knowledge is] anything that is known by somebody and as 'production of knowledge' any activity by which someone learns of something he or she has not known before, even if others have. (Machlup 1980, p. 7)

It is interpreted both as the state of knowing and the body of collected truths, facts or wisdom:

Knowledge
1. acquaintance with the facts, truths, or principles, as from study of investigation; general erudition.
2. familiarity or conversance, as with a particular subject, branch of learning, etc.
3. acquaintance; familiarity gained by sight, experience, or report: a knowledge of human nature.
4. the fact of state of knowing; perception of fact or truth; clear and certain mental apprehension.
5. the state of being cognisant or aware, as of a fact or circumstance.
6. that which is known or may be known.
7. the body of truths or facts accumulated by mankind in the course of time.
8. the sum of what is known.
9. cognisance of facts, or range of cognisance: this has happened twice in my knowledge.

(The Macquarie Dictionary, emphases in original)

Thus knowledge applies to both a state of the knower (definitions 1, 2, 3, 4, 5, 9 above) and that which is known (6, 7), but this distinction is not always made clearly (8). This chapter will address all three possibilities, namely what it means to have scientific knowledge, the body of scientific knowledge, and discussions about knowledge that do not distinguish clearly between the two. The claim that having scientific knowledge is a state of the knowing individual and not of science is included in the present thesis, but along with views that oppose it. The objection itself arises from particular views of
science and epistemology, and is opposed by other views; the present thesis explicitly seeks to establish a framework that will enable comparison of all views, and so includes this objection as one view. Secondly, the collection of summary statements, and other arguments in the literature, do not restrict the notion of knowledge in this way: in the literature, science is characterised by knowledge as a particular state of knowing, by knowledge as a body of knowledge, and sometimes by knowledge as an indistinct notion. Therefore this thesis addresses each possibility.

This chapter will argue that knowledge is a necessary dimension of science in that the meanings of characterisation in the metascientific literature are incomplete without it, and that the meanings of the other proposed dimensions will not substitute for its omission. It is not a sufficient dimension of science in that it does not completely characterise science. Where science is characterised by knowledge, usually it is characterised in combination with one or more other dimensions of science: activity, purpose, context, structure and belief system.

These other dimensions are used in explicating scientific knowledge, and scientific knowledge is used in explicating the other dimensions. Thus scientific knowledge is not simply any knowledge, but knowledge characterised by its association with particular activities, purposes, contexts, structures and belief systems. We have noted earlier that knowledge is one of the two commonly used dimensions for characterising science, and the metascientific literature is replete with detailed discussion and debate about the nature and significance of scientific knowledge. The present chapter, together with Appendix B.6, will make selective use of these accounts only, to suit its purpose. In so doing it will attempt to strike a balance between including sufficient detail to construct the argument and not repeating detail available in the literature.

The argument in this chapter comprises four parts:

1) evidence from the analysis of the summary statements;
2) evidence from argument in the metascientific literature;
3) the relationships between the dimension of knowledge and the other dimensions;
4) conclusions for use in theorising about the science curriculum.
1. Evidence from the summary statements

Knowledge as a partial dimension of science is indicated in the summary statements from the metascientific literature collected in Figure A.1. The collection of classes (in Table A.3) and text units from the differentiae (column one of Table A.9, headed Knowledge), collectively indicate that science is characterised partly by knowledge, concepts, conclusions, facts, informative content, notions, common sense or understanding. As with the other dimensions, this category of characterisation was constructed from a semantic analysis of many metascientific sources. Thus it includes a wider range of viewpoints than do many individual accounts in the literature.

Providing examples of text units meaning knowledge is straightforward: we have noted earlier that knowledge is one of the two common dimensions of characterisation. Thus, as we have mentioned, knowledge in science is taken to mean the body of received knowledge:

For nearly any body of knowledge that is sufficiently organised to exhibit appropriate evidential relationships among its constituent claims has at least some call to be seen as scientific. What makes for science is system, whatever the subject. (Quine 1978, in summary statement 37)

or of personal knowledge:

The creation of scientific knowledge 'begins with the plain and unembroidered evidence of the senses, with innocent, unprejudiced observation ... and builds upon it a great mansion of natural law' (Medawar). (Mulkay 1979, in summary statement 47)

or is indistinct:

Scientific knowledge is experimental knowledge. It is characteristic of scientific research that observational evidence plays a crucial role in the resolution of the issue between contending hypotheses, and whatever sort of objectivity scientific inquiry has depends crucially on this feature of the scientific method. (Boyd 1991, in summary statement 50)

Here is a selection of text units from just the first twenty summary statements, showing the use of knowledge in characterising science:

- knowledge so obtained [from] systematic study
- systematised knowledge in general
• a particular branch of knowledge (1)
• a better understanding of the natural world (3)
• a developing body of knowledge - observations, concepts, laws and theories (4)
• a domain of human knowledge (5)
• systematic organisation of knowledge (5)
• knowledge about the universe and its parts (5)
• facts (7)
• search for understanding (8)
• this understanding being codified in statements (8)
• search for understanding expressed in laws or principles (9)
• conceptual generalisations (11)
• a way of knowing (12)
• a set of conclusions or a body of knowledge (14)
• scientific conclusions (14)
• facts (15)
• not even simply an accumulation of knowledge (16)
• a highly integrated form of knowledge which makes a world view (16)
• common sense (17)
• general understanding (18)
• knowledge (18)
• a knowledge producing and knowledge improving enterprise (19)
• a paradigm, or conceptual structure (20)
• empirical epistemology (20)
• explain and understand (20)

Note the inclusion of laws and theories from statement 4. The present thesis interprets laws and theories as cognitive structures, or structures of knowledge, as in body of knowledge. Other statements within these first twenty also mentioned laws and theories, but we have not included them in this list, preferring to discuss these terms separately, here. We have discussed in chapter 4 phrases, commonly used, such as body
of knowledge or set of conclusions, that could be interpreted either as structures (body, set) or knowledge (knowledge, conclusions), or both. The present thesis, in seeking to address all characterisations, accepts both interpretations. Explications of law and theory in the literature clearly characterise them as both knowledge and structure (and often other dimensions, notably beliefs, purposes and activities). This does not imply that the proposed categories of characterisation are insufficient to neatly house law and theory in just one category; rather, it shows that the categories are useful in explicating different characteristics of complex notions such as law and theory. This is the function the present thesis seeks to serve. Thus we acknowledge the use of law and theory as knowledge terms.

However, law and theory are addressed in the companion chapter on structure (with the associated metascientific argument in Appendix B.4), for several reasons. The principle reason is that the present thesis argues that law and theory, like all the characteristic terms it analyses, have a multidimensional character. However, it would be repetitious to treat these terms, like law and theory, in each of the four, five or six chapters that apply most strongly. Instead, the strategy has been twofold: to treat most terms in one, or sometimes two chapters to show how they are characterised in those dimensions; and to show in part 3 of the companion chapters how the dimensions actually work in combination. Laws and theories are clearly characterised by knowledge, but the present thesis treats them mainly in the discussion on structure to draw the reader’s attention to their structural dimension. Laws and theories also arise within, and derive part of their character from, their contexts, especially their intellectual contexts. However, to explore every element of characterisation for every scientific term and characteristic is well beyond the scope of the present thesis, and in any case would belabour the point.

Although knowledge is used commonly to characterise science, its meaning is not commonly made clear. There is a considerable literature devoted to arguing variations, subtleties, complexities and a broader scope of what knowledge is, and how it characterises science. The following section, and Appendix B.6, highlights some of these arguments most relevant to the present thesis.
2. Evidence from argument in the metascientific literature

This section mentions some of the argument in the literature that characterises science by knowledge, reviewed in Appendix B.6. Although knowledge is one of the two dimensions traditionally used to characterise science, this association did not make the present analysis necessarily easier: tradition is not sufficient reason to substantiate an analysis of this type, and exactly what we mean by knowledge is rarely explained in general science texts, other than to address fields or disciplines of knowledge. When we turn to the metascientific literatures, there are strong and diverse views about the nature of scientific knowledge, whose complexity is compounded by views in other literatures, such as psychology. In informal discussions with a number of scientists and science educators during the writing of this thesis, most viewed scientific knowledge primarily as a list or map of knowledge content, but this characterisation alone is unsatisfactory. With some prompting, most agreed that science knowledge was more problematic than this, as discussed in the metascientific literature, and in any event attempting to provide a comprehensive map of such content could never be definitive. Related to its often unspecified use, the term knowledge is used commonly in conjunction with one or another of several other terms, for example belief, understanding and information, whose meaning and relationship to knowledge are likewise often imprecise and interpreted variously. Appendix B.6 delineates some of these uses and relationships in characterisations of science, and is set out as follows.

B.6.1 Current metascientific views of knowledge

The variety of metascientific views characterise science knowledge and its role differently. These are summarised in Table B.6.1.

B.6.2 Illustrating an historical tradition of science by knowledge

The history of western European science is characterised partly by the development of knowledge. Traditional histories tend to trace the successful ideas, meaning those interpreted as precursors of later ideas. Thus these histories characterise the development
of scientific knowledge as the progressive march of history. Developments in historical scholarship have meant that contemporary approaches tend instead to evaluate historical episodes from within their own contexts, rather than judging with hindsight.

B.6.3 Knowledge and belief; standard definitions of knowledge

Science is often characterised by knowledge in association with belief, where knowledge is taken as a more secure form of belief. The standard definition of knowledge in epistemology is that knowledge is justified true belief, although this has more recently been subject to philosophical attack for which there is no agreed answer.

B.6.4 Kinds of knowledge

a) knowledge how and knowledge that

b) internalist and externalist theories of knowledge

Science is characterised sometimes by particular kinds of knowledge. While there is no philosophically or sociologically distinct kind called science, much of philosophical analysis has centred on propositional knowledge, or knowledge-that; this is commonly taken to be the ‘knowledge content’ of science. Propositional knowledge-that comprises empirical knowledge, derived by induction from observation statements, and a priori knowledge, derived by deduction from axioms or assumptions. Practical knowledge-how also characterises science, as argued in post-positivist philosophy and sociology of science. The content of science knowledge is characterised in some views as arising only from the mind of the individual (internalism), but in other views as also arising from factors like the physical and social environments (externalism).

B.6.5 Knowledge and information

Science is also characterised sometimes by knowledge in the sense of data, facts and information, both as a state of knowing and as that which is known. These terms usually refer to the elemental contents of science knowledge and so mean a state of knowing that is less certain than understanding. Data and information are particularly interesting because of their astonishing increase in recent decades, known by terms such as the information revolution or knowledge explosion.
B.6.6 Knowledge and understanding

Science is characterised sometimes by knowledge in the sense of understanding, meaning knowledge that is reasoned. Understanding usually means knowledge of the underlying argument or of the implications, and is therefore more complex than simple recall of data. The sheer volume of science knowledge in the sense of data or information means that a personal understanding of it all is impossible. The public understanding of science is the subject of a substantial literature itself, and is interpreted variously.

B.6.7 Knowledge as concepts and propositions

Science is also characterised by knowledge in the sense of concepts and propositions. Propositional knowledge—that comprises statements that affirm or deny a claim. A concept is a generalised term for a number of entities that are similar in some way. Concepts and propositions typically comprise the knowledge content, in science and elsewhere.

B.6.8 Knowledge and power

Science is also characterised by knowledge as it applied to power and usefulness, usually as its ability to predict.

B.6.9 Knowledge as a map of scientific content or topics; current scientific conceptions

Science is also characterised by knowledge in the sense of a map of scientific content. This is now often a reference to the information explosion, where any attempt at a complete map is nonsensical, but it also applies to lists and categorisations, as for example as the list of contents in science texts, in maps of science fields and disciplines, in published sources like journals and in dissertation abstracts.

Knowledge as a necessary dimension

The argument to this point of the chapter and in Appendix B.6 establishes knowledge as a (semantic) category of characterisation in the literature: knowledge is used
in a number of senses, and from a number of theoretical positions. Thus at the broadest level, knowledge is used in the sense of a knowing (or cognitive) state, as a body of statements, or in a sense that does not distinguish clearly between the two. Theoretical differences centre on a tension between the view that science knowledge arises directly from sense experiences (a strong empiricism or positivism) and the view that it is a mental construction (constructivism). There are a number of plausible middle-ground positions that acknowledge both the central role of observations in forming science knowledge, and mental and social activities in the actual construction of knowledge.

These arguments do not in themselves establish knowledge as a necessary dimension, but their contribution to metascientific discussions does: metascientific discussions commonly appeal to knowledge in characterising science as a central element of science. That is, science is centrally concerned with knowledge: as the knowledge content (of the cosmos); as knowledge structures like theories, propositions, and some senses of disciplines, fields and domains; as knowledge-how and knowledge-that; as justified or reasoned beliefs (understanding); as elemental units of facts and information; and as networks of generalised ideas (concepts). Characterisations of science fail if we remove these references to knowledge. There is an immense literature addressing these elements, that includes different interpretations of them. To understand the nature of science knowledge, one must at least be aware that the literature construes science knowledge in these various ways and, ideally, understand at least some of the insights of the major positions. As with the other categories of characterisation, to recognise only a single position from the literature is to fail to understand that there may be plausible alternatives, and hence possible alternative insights, and especially to be unable to defend a particular view from the attack of other views. One cannot appreciate the strength of a claim to science knowledge without appreciating the strength of alternative arguments. It follows that to understand science, one must: first, understand the central role of knowledge in characterising science; secondly, appreciate the diversity of accounts of this knowledge; and thirdly, appreciate the insights of some alternative characterisations.
3. Relationships between the dimension of knowledge and the other dimensions

Knowledge is used pervasively to characterise science, and many examples show the interrelationship between knowledge and the other dimensions. We will review some examples here.

Science knowledge in the twentieth century and scientism

A suitable illustration of the interrelationship between knowledge and other dimensions is the nature and place of science knowledge in the twentieth century. It is commonly accepted that scientific understandings change with time; Table B.6.2 gives some examples. Indeed, science histories typically emphasise the historical development of science knowledge, rather than, say, scientific activities or institutions. The history of both science and metascience give a much more robust appreciation of the nature of contemporary science (Matthews 1994). Metascientific analysis shows that science knowledge has changed and will to continue to change; further, our understanding of it is also likely to change. These are powerful insights. They challenge the traditional characterisation of science knowledge as a body of eternal, that is, unchanging, truths. However, the characterisation of science knowledge as authoritative is supported by its utility, making it a valuable resource to both scientific and general cultures.

A second characteristic of science knowledge in the context of the twentieth century is the increasing links between science, technology and policy, notably through industry and government, as mentioned already. The knowledge, activities and purposes of science are increasingly obscure to the lay observer, who, through increasingly disparate specialisations, may be a scientist whose expertise is in some other field. For example, the equipment that characterises much current scientific activity is often electronic and its functions result from the action of silicon chips on circuit boards and other apparatus concealed inside a sealed box. This contrasts with the equipment familiar to citizens from their school Science, whose workings can be deduced mostly from external examination
and resemble instead the equipment of J. J. Thompson's physics laboratory barely a century ago.

A third characteristic is that, inevitably, science knowledge develops sometimes before ethical, cultural, political, legal and other factors, as with, for example, *in vitro* fertilisation, and the cloning of mammals. When science is embroiled in these ethical and other disputes its image - its popular characterisation - as neutral, value-free, objective knowledge is questioned in the public arena and, increasingly since the 1960s, rejected. Also, as science has increasingly served industrial and military ends, its expense, purposes and underlying beliefs and values - and hence its knowledge claims - have been disputed in the public arena. Certainly it presents choices to the community, but as we discussed in the companion chapter on context and Appendix B.1, citizens' abilities to make informed decisions about the choices is a contentious issue, and interpreted variously. The resulting inaccessibility of science to democratic processes has fuelled sentiments of alienation, mistrust and criticism of science:

Today's controversies reflect a long history of public ambivalence toward science in American society (Mazur 1981). The acceptance of the authority of scientific judgement has long coexisted with mistrust and fear, revealed, for example, in the early opposition to innovations such as vaccination or to research methods such as vivisection. The romantic view of the scientist as a 'modern magician', a 'miracle man [sic] who can do incredible things,' has been paralleled by the negative images of mad scientists: the Dr Frankensteins and Dr Strangeloves that pervade popular culture (Rozak 1974, p. 31).

In part, public ambivalence has been a response to the obscurity and complexity of science that appears to threaten the power of the citizen. The growing importance of expertise in policy decisions seems to limit the democratic process (Goggin 1986). Activists demand greater involvement in decisions about science and technology, seeking participation in review boards and decision-making groups. However, only about 5% of American adults are both attentive to science policy issues and sufficiently literate scientifically to understand and assess the arguments underlying the disputes (Miller 1990). Thus disputes often have less to do with specific technical details than with broad political issues: They represent the growing polarisation between those who see scientific and technological developments as essential to social progress and those who see these developments as driven by political or economic interests (Richards 1988); between those with programmatic agendas seeking to implement specific goals and those with moral lenses concerned about accountability, responsibility, and rights. Some controversies (eg., over the superconducting supercollider) remain mainly at a policy level where issues are debated by experts, ethicists, and policy elites. Other (eg., over the use of animals in research) are public protests engaging social movements and citizens groups. Sometimes concerns have less to do with the implications of science and technology than with the power relationships associated with them ... (Nelkin 1995, pp. 446-7)
The present thesis interprets Nelkin’s critique as arguing that late-twentieth century science knowledge is characterised partly by its use in public disputes, whose resolution involves understandings not just by scientists but in many cases also by other interested parties. This also involves scientific activity: by implication, the design, execution and interpretation of experiments are contested as parts of the disputes.

The present thesis argues that knowledge (concepts) and (experimental) processes alone account for neither disputes over the intellectual content nor socio-political issues: they are understood much better using the multi-dimensional characterisation proposed here. Thus the supercollider example is characterised also by: a restricted context (participants are those with demonstrated and accepted expertise - experts, ethicists, and policy elites); activity (involvement in decisions, debate of the intellectual content or knowledge); structure (of groups vying for expert status, and funding and approval bodies); purpose (programmatic agendas seeking to implement specific goals); and belief system (the assumptions and priorities of experts, ethicists, and policy elites). On the other hand, the example of animals in research is characterised also by: a broader context (social movements and citizens groups, who by implication involve expert groups or individuals where necessary as resources); activity (public protests); structure (there is a contrast between organisations like review boards and decision-making groups, and social movements and citizens' groups); purpose (citizen concern with science being driven by political or economic interests); and belief system (moral lenses concerned about accountability, responsibility, and rights). Both examples entail an obscure and complex structure of science, which either precludes citizen participation, as with the superconductor, or provokes it, as with vivisection.

Another characteristic common to both types of examples is that they make complex appeals to the character of science knowledge. Where the context is restricted to ‘experts’, the involvement of policy elites signals questions of competition for funding, as with the supercollider debates, or broader political issues. So even in these contexts, decisions are not made solely on the grounds of the intellectual content of science knowledge. Thus Bimber and Guston (1995) characterise the US debate over superconducting...
supercolliders as an example of characterising science as exceptional because of its unique contribution to the economy:

The fourth category of argument [that science is exceptional] involves economic exceptionalism. It relies on the claim that science is a uniquely productive investment of current resources for future gain. In the United States, supporters of a federal role in scientific research have been advancing such a claim since the nation’s founding, privileging science by protecting intellectual monopolies under the US. Constitution ...

Recent calls for a redoubling of the US. academic research effort (Lederman 1991) have cited at least one analyst who claims to have documented extraordinary rates of return for investments in scientific research (Mansfield 1991). One need look no further than the justifications that scientists offered for enormous expenditures on the superconducting supercollider, for example - in the presence of a crippling budget deficit - to see the conviction with which many are willing to argue for the economic specialness of science. (Bimber and Guston 1995, pp. 558-9)

That is, even in this example of so-called ‘pure’ science research, the question of whether or not to proceed with the research does not rely solely on its intellectual merit, but on a broader context of arguments such as the level of government funds allocated to scientific research instead of some other policy area. Gieryn (1995, p. 436) has argued that the relationship between science and government is very complex, where both government and the science community try to keep the boundary between the two close ‘but not too close’:

The dilemma for policy makers (in the broadest sense) is clear: Bring science near enough so that political choices are legitimated by their perceived grounding in authoritative and objective understandings of the facts as only science provides, but not so close that choices and futures become exclusively ‘technical’ and beyond the grasp and thus control of non-scientists. Scientists also need to keep the fence on their ‘politics’ frontier well mended. After all, what makes scientific knowledge useful for politics is not just its content but its putative objectivity or neutrality. Science can legitimate policy only if scientists are not treated as just another interest group and their technical input is not defined as just another opinion. Spillover in the other direction - from politics into science - is just as dangerous for scientists’ autonomy: When politicians themselves make facts, the professional monopoly of scientists over this task is threatened. An even more likely threat is the capture of science by policy-making powers - a loss of scientists’ control over their research agendas and, in the limiting case, over what is represented as ‘scientific’ knowledge. (Gieryn 1995, p. 436)

Appendix B.1 on context discusses this at greater length, including examples from US and Australian government science policy. Thus scientific knowledge, even in pure science, has a complex characterisation partly by context.
Where the dispute involves public (lay) participants, such as the debates over vivisection or fluoridation, the role of context in characterising science knowledge is even clearer. The authoritative, objective and neutral status of science knowledge is central, and used as a resource by all sides in such debates. For example, Yearly (1995) has argued that research into environmental issues continues to be dominated by ‘top down’ projects from ‘funding agencies and their political controllers’; there have been surprisingly few ‘radical research initiatives to appear in a bottom-up way from the scientific community’ (p. 476). Despite this, however, ‘academic and institutionally independent scientists still play a central role in analysing environmental issues’ (pp. 476-7).

Thus both sides value the independence of the science knowledge: they contest the debate by valuing the authority of the science knowledge that suits their purposes, and question scientific authority that suits their opponents’ purposes. Yearly provides a nice example of Greenpeace questioning the neutrality of science faculties that rely on external funding, and the counter claim of the UK Atomic Energy Authority questioning the independence of the University of London because it hosts the Greenpeace International Science Unit. This is common in public disputes involving science:

The authority of scientific enterprise has rested on assumptions about scientific neutrality (Proctor 1991). The interpretations and predictions of scientists are judged to be rational and immune from political manipulation because they are enlisted by all sides of disputes. Just as industrial advocates use technical expertise to support their projects, so too do the protest groups who challenge them...

Though political values or moral issues may motivate disputes, the actual debates often focus on technical questions. Quality of life issues are discussed in terms of the physical requirements for a disputed facility or the accuracy of risk calculations rather than the needs or concerns of a community. Concerns about the morality of foetal research are reduced to debates about the precise point at which life begins. This displacement of issues can be tactically effective, for in all disputes broad areas of uncertainty are open to conflicting scientific interpretation. When decisions must be made in a context of limited knowledge, and there is seldom conclusive evidence to dictate definitive resolution, power may hinge on the ability to manipulate knowledge and to challenge the evidence presented to support particular policies. But as technical expertise becomes a resource, exploited by all parties to justify competing moral and political claims, it becomes difficult to distinguish scientific facts from political values. Debates among scientists reveal the value premises that shape the data considered important, the alternatives weighed, and the issues regarded as appropriate (Hilgartner 1992). (Nelkin 1995, p. 452-3)
The present thesis interprets this passage as characterising science knowledge not just by context, but also by belief system and purpose. The belief system includes assumptions about scientific neutrality, judged to be rational, value premises and the assumption that political values and moral issues characterise the non-scientific aspects of disputes are all elements of the science belief system used. Purpose is more implicit, but is given as the focus on technical questions, the notion of effective tactics, evidence presented to support particular policies, and political values. The arguments in the companion chapters on belief system, purpose and context and their respective appendices show that the interpretation of Nelkin and Yearly, above, will depend on how one characterises science and the interpretive perspective used.

A moderate internalist argument is that, although funding and policy issues affect science, and the ultimate application of science knowledge, the work of scientists is essentially buffered from these factors, and purely cognitive criteria and beliefs are applied in (ideally) rational and objective ways. The evidence is weighed by scientists, as in publication in refereed journals within a shared belief system. Competing knowledge claims from different research efforts thus still need to be evaluated using scientific criteria, that is, the criteria agreed to and used by the particular community of scientists. This can be better understood by addressing the belief systems underpinning the competing knowledge claims. It is this evaluated knowledge that is then used more widely by society. In partial contrast, another moderate externalist argument is that the funding and policy priorities and decisions determine what problems are identified and investigated, and science knowledge cannot be divorced from these constraints. Argument presented earlier, such as from Bhaskar, Ravetz and Longino, make a plausible claim that scientific knowledge has an inherently social character and cannot be reduced to a strictly internalist (cognitive) structure, without requiring a strong externalism. As with other examples across the companion chapters, a moderate externalism seems most defensible.
4. Conclusions for later use in theorising about the science curriculum

This section extends the argument, developed above and in Appendix B.6, that science knowledge is a necessary dimension of metascientific characterisations of science, to claim also that it should form part of school Science. This is not the same as arguing simply that school Science should include science knowledge and concepts: we have noted that science is commonly characterised by knowledge already, and that school Science traditionally emphasises knowledge. The present section argues a stronger case, that school Science should embody a richer, or more complex, notion of science knowledge as it is characterised in the literature of its field.

I. Findings about the nature of science knowledge from the review of the metascientific literature.

There is a range of currently accepted views of science in contemporary scientific, philosophical, sociological, historical and linguistic analysis, that characterise science by various notions of knowledge. There is no simple, clear and universally agreed explanation of science knowledge. Examples given in this chapter can be summarised as:

There is a range of views of science knowledge.

a) Different metascientific perspectives offer different notions of knowledge in science, as given in statements arising from: perception, in empiricism; mental construction, in constructivism; or given in an external reality, but socially and psychologically constructed, in scientific realism.

b) There are different kinds of knowledge proposed, of which the kinds that mostly concern the present thesis are practical knowledge-how, and propositional knowledge-that; there are two kinds of knowledge typically regarded as knowledge-that.
c) One kind of knowledge—that is a priori knowledge, which ‘is derived from its self-evident axiomatic bases by deduction ... [and] is said to come from reason.’ (Quinton, 1988, p. 279)

d) The other kind of knowledge—that is empirical knowledge, which is derived from ‘uninferred observation statements by deduction ... [and is usually said to derive from] sense perception and introspection.’ (Quinton, 1988, p. 279)

e) Traditional accounts of science knowledge, that derive from positivism, have emphasised the rational reconstruction of knowledge-that, and have paid scant attention to, or have rejected, knowledge-how because it cannot be rationally reconstructed.

f) Post-positivist metascience has sought to explain the role of knowledge-how in science, notably the knowledge that is entailed by the craft-like character of scientific activity (Ravetz), and tacit knowledge (Polyani).

g) The literature discusses knowledge in science in several senses: as a body of knowledge, as in a published body of concepts and propositions; as a state of knowing; and in senses that do not clearly distinguish between the two.

Knowledge is related to belief.

h) The association between knowledge and belief has a long history (notably from Plato) and is found in popular uses of the terms: knowledge entails belief, but is more secure because it is reasoned.

i) The standard definition of knowledge in epistemology is that propositional knowledge is justified true belief: that is, it must satisfy the three conditions, justification, truth and belief. While this definition once commanded almost universal agreement in epistemology, it is no longer agreed to define certain knowledge. Most responses in epistemology seek a fourth condition, although none is agreed yet; many responses in sociology and some in philosophy hold that criteria like justification, truth and belief are not absolutes, and instead are relative or contingent.
There is debate about what determines knowledge and beliefs: there are two broad positions, internalism and externalism, although these terms are used in two senses.

One sense of internalism and externalism is a restricted one in epistemology: either beliefs can be justified only by the internal states of the believer (internalism) or by more than the believer's internal states.

The other sense of internalism and externalism is broader, as used in history and sociology of science: either the content of knowledge and beliefs is determined by intellectual or cognitive factors (internalism), or it is determined by social, political and other factors as well as, or instead of, internal factors (externalism). This is the sense discussed in the companion chapter on context and Appendix B.1; internalism and externalism are only categories to help analysis, and extremes of either should be avoided (Morrell 1983a, 1983b), and debates between the two camps have been marked by caricature and have not yet resolved many issues (Shapin 1992).

Science is characterised by knowledge as information, facts and data

Science knowledge is characterised by elements of knowledge—that, in the sense of information, facts or data. In the sense of a knowing state of the individual, possession of the relevant information, facts or data is interpreted usually as necessary for having science knowledge, but not sufficient because they do not require reasoning or understanding.

Information, facts and data are also elements of science knowledge in the sense of the body of knowledge that is external to the knowing individual: that is, the body that is available but not necessarily known by the individual. This is the knowledge available in textbooks, journals, on the Internet, in databases, and so on.

The amount of information, facts and data that is produced by scientific activity has always been increasing, but is now so large and increasing at so great a rate that it is difficult for any individual to keep track of it, and impossible to know it
personally. This has been described by various terms such as the *information explosion*.

p) The effects of the information explosion on society and science have been interpreted variously as beneficent, malevolent, or neutral.

q) Each of these interpretations is arguable and simplistic: the present thesis argues that it is more sustainable to characterise science by a combination of knowledge, context, purpose, structure, activity and belief system, where they arise often from more than one perspective.

*Science knowledge is characterised by being reasoned and having understanding.*

r) Science knowledge is characterised by understanding: in the sense of a state of the knowing person, it means to comprehend the significance of, and reasoning behind, a proposition of knowledge.

s) In the sense of a body of knowledge, an understanding usually means a statement that is a proposition *that* \( p \), where \( p \) is a predicate that affirms or denies a claim.

t) Knowledge-that is expressed typically as propositions.

u) Propositions are statements that typically express an understanding about concepts, where concepts are generalised terms that label a group of similar ideas, like *planet* and *animal*.

v) Concepts are important in understanding science knowledge, because they enable the individual to respond to classes or groups of entities - objects, relations or properties - rather than a multitude of individual instances.

w) Science knowledge is conceptually complex, and has become increasingly so in the twentieth century.

x) Furthermore, science concepts often differ from concepts in a 'commonsense' view of the world; this has implications both for the science education of both scientists and citizens generally.

y) The public understanding of science and science issues was characterised traditionally as a 'deficit' on the part of the public: that given the right
information and/or training they too would understand the 'correctness' of the science knowledge. Typically, this assumed a particular, uncontested, authoritative view of science knowledge. It is a view of public understanding and science that remains widely accepted despite strong criticisms.

z) More recent studies of the public understanding of science have also examined the ways in which competing public science disputes construct and exploit alternative meanings of science knowledge: the ways in which science knowledge is revisable and contested within the science community, and the ways in which 'folk' knowledge is useful for citizens regardless of its formal endorsement by the scientific community.

*Science knowledge is characterised by power and authority*

aa) As discussed in the companion chapter on context and Appendix B.1, science knowledge has traditionally been equated with power, because of its predictive and explanatory success; this association dates at least from Francis Bacon.

bb) The correlation between the power of western societies and the practice of western European science was held traditionally to demonstrate the intrinsic rationality and power of western European science: science was thus the paradigm of rationality.

c) Following analyses that showed both predictive power in non-western systems of knowledge, and flaws in traditional, positivist accounts of western science, some accounts now seek to explain the success of western European science without denying the power and usefulness of other knowledge systems such as indigenous knowledges.

d) The authority of (western European) science knowledge has meant that the image of science is frequently used either to convey or deny authority to arguments or knowledge systems. The present thesis interprets this as associating knowledge claims with other dimensions of science, namely scientific structures (such as scientific language), activities (such as experiment), beliefs, context, or purpose.
Knowledge as a map of scientific content

e) The content of science knowledge is commonly taken as a 'map' of scientific content, although the present thesis argues that other dimensions, such as the belief system, activities and purpose, have the same content.

ff) Histories of science are typically histories of science knowledge, and show clearly that the content of science knowledge changes.

gg) Given its constantly changing and expanding character, it is not plausible to try to give a detailed map of current science knowledge.

hh) Knowledge as a map of science content can be interpreted in several ways, each of which being limited but offering useful insights: as concerning the material world; as the disciplines, fields or domains of science, where they are taken as cognitive, not organisational, structures; and as the body of refereed, scientific publications.

II. Implications for a school Science that reflects the metascientific literature.

Although current school Science curricula, in Australia and elsewhere, are centred moderately or strongly on knowledge, they do not present a comprehensive characterisation of science knowledge as found in the metascientific literature. One example is that they do not address the present and future volume of science knowledge. Stonier made this point in a critique of physics teaching in Great Britain:

Micro-electronics in its various shapes and forms is propelling society into a new era as different from the industrial era as that era was from the Middle Ages. Imagine my astonishment at finding how little is taught about solid state physics, transistors, how micros work, what is the historical development of this technology, what are some of the likely future developments. It is true that there exists options to learn about electronics and micro-electronics - but they appear to be limited. The teachers frequently appear to have little idea of what is shaping up in the future (e.g. cryogenic micro-electronics), or other ideas of related technology. (e.g. photovoltaics) and certainly little about the history of the technology, which could be one of the most fruitful ways of introducing physical concepts. Needless to say, I did not expect that students might have discussed the implications of these developments on employment patterns, the home, changing lifestyle, or warfare. Heavens forbid! (Stonier 1987, p. 106)
To be fair, there are some fairly obvious rejoinders to Stonier we should mention before pursuing his critique. First, we have noted that the sheer volume and scope of science knowledge are immense and expanding rapidly, so the science curriculum can always be open to the charge that some particular area of knowledge has been left out. Secondly, school practical work in electronics is expensive, far more so than for the equipment that would suffice for teaching basic concepts of electricity and electrical circuits. Thirdly, the concepts of electricity and circuits are regarded usually as more fundamental than for electronics, and given the pressure for curriculum time from the volume of potential science knowledge content, to go beyond basic electrical concepts means denying time for some other area of content.

Fensham (1992, p. 800) has made a similar point about school Science knowledge not representing the massive advances in science knowledge. Other calls for revision of school physics and chemistry aside, he is critical on two counts. First, school Science, particularly chemistry, is still concerned with general concepts and abstract principles, rather than an understanding of field and laboratory experiences of chemical reactions. Secondly, it is concerned with basic chemicals long used in school laboratories rather than ‘in terms of newer substances with quite novel properties’.

The comments on Stonier’s analysis aside, his and Fensham’s basic criticism stands: the school Science curriculum does not reflect well the character of science knowledge, as the analysis of the literature by the present thesis shows.

There are responses to each of the three objections to Stonier given above. First, while a school Science curriculum cannot address the quantity of science knowledge, it should indicate the scope and areas of rapid development. Secondly, while much of the more recent science requires more sophisticated and expensive equipment, providing resources for practical equipment is only one of the issues that arise. To the extent that the scope for practical activities ‘drives’ the inclusion of electronics or other fields in the curriculum, there is a general resourcing response that will arise from the commitment of the community to provide the resources, and other, particular solutions: some schools use commercial electronics kits, and universities, for example, use software that enables
students to design, 'construct' and test circuits on screen. But Stonier is urging schools to
address more than circuitry activities: he argues that the past, present and potential social
impacts are important for citizens and scientists alike to understand, and students can
learn about them by doing other activities. Thirdly, the notion that the more fundamental
concepts, suitable for school students, are those in the more established areas of science,
is an assumption only. STS and HPS approaches to science education, for example,
suggest rich areas of interest and utility that are largely untapped by traditional science
curricula and that offer fresh approaches to teaching science content.

Also, the considerable literature on constructivism in science education shows that
teaching science concepts is not straightforward, and that children form various
understandings of concepts, often at odds with the intention of the teacher and
curriculum. While there are examples of recommendations for teaching concepts more
effectively, there has been relatively little for designing a science curriculum. Thus at least
some of the difficulty with learning science concepts has to do with learning and teaching
activities, and does not arise solely from some characteristic inherent in science concepts.
While science learning and teaching issues are beyond the scope of the present thesis, the
constructed character of science knowledge advocated in many contemporary views
should feature in school Science knowledge.

A second example of a fundamental flaw in typical school Science is the emphasis
on proto-university knowledge content. This has strong implications at least for science
literacy and the public understanding of science, which Shamos has argued should focus
more on knowledge-as-understanding, including metascientific understandings:

Contrary to what most science educators contend, knowing science in the formal
academic sense may not be a necessary condition to attaining scientific literacy in
the social sense. However, knowing what science is about is prerequisite to such
literacy. The distinction may seem subtle at this point, but it is nonetheless
important. We will never get the mass of our population to understand science in
detail, but we may be able to instil some understanding of how the enterprise
works and how scientists practice their discipline - enough, one hopes, to serve
the societal purpose of scientific literacy. (Shamos 1995, p. 45)

To the extent that the school Science curriculum reflects the literature, and the
present thesis argues that a curriculum must in order to demonstrate its rigour, then the
curriculum must present a more robust and coherent characterisation of science
knowledge than simply a selection of science concepts as content. Such a characterisation will show that there are different views of what constitutes science knowledge, and in particular that it includes practical knowledge-how as well as propositional knowledge-that. That is, the curriculum should not be content for students merely to experience science activities, but to develop a practical knowledge-how - some of what Ravetz called the *craft skills* of scientists - as stated outcomes or objectives. Students should develop an appreciation of how and why knowledge is distinguished from belief, and should be encouraged to develop reasoned understandings rather than memorisation for recall of simple collections of data. That is, a robust characterisation of science knowledge will entail covering less content but more thoroughly so as to develop understandings. Students should develop an appreciation of the status and source of information, facts and data, and their rapid expansion. This will entail developing skills for accessing, evaluating and using data and information. Students should develop an appreciation of the power and authority of science knowledge, which includes appreciating its limits. This will entail students learning to identify and evaluate appeals to scientific knowledge in both the science literature and public forums. Finally, students should develop an appreciation of the scope of science knowledge, which includes fields that are developing rapidly. This will entail students learning how to locate and evaluate updated information and claims of science knowledge. The current increase in the use of microprocessor technologies is a suitable range of strategies for these propositions. As transmitters of information, schools are already battling to compete with information from TV, satellite transmissions, domestic video recorders and existing computers that are better-researched and more appealingly presented. New microprocessor technology is more flexible, 'controllable, interactive, up-to-date and client-oriented' (Meighan & Reid 1982, p. 375).

A more robust and coherent characterisation will also characterise science by knowledge in combination with activity, context, structure, purpose and belief system. Thus the science curriculum should not be strongly reductionist, although that strategy might suit sometimes: it should demonstrate the holistic character of science knowledge, rather than a fragmented conceptual framework. Numerous studies in science education...
show that learning science is enhanced when the knowledge is presented in some meaningful context, and that student disaffection with science is related strongly to the acontextual character of the knowledge presented; this is an argument from pedagogy and learning theory. The present thesis supports this argument from the scientific and metascientific literature: science knowledge is only partly, and unclearly, characterised by its content; it is also characterised by particular activities, contexts, structures, purposes and belief systems.

Finally, the earlier review of the science education literature, particularly that of the constructivists such as Driver, show that different learners can develop or construct different, individual understandings from apparently identical learning stimuli. This demonstrates an inequality between public knowledge with private understandings. This inequality is partly discussed by the present thesis in addressing the public understanding of science. However the constructivist science education literature is beyond the scope of the present thesis and except for acknowledgment of the significance of children’s individual understandings and beliefs, is not addressed.

Some specific recommendations corresponding to the summary of findings in part I above:

Throughout the following, students should develop an appreciation of science knowledge as part of developing a multidimensional characterisation.

There is a range of views of science knowledge.

a) Students should develop an appreciation of different views of how we develop knowledge of the material world, specifically through perception and mental activity. For example:
   • Students should have opportunities to identify the basis for knowledge claims, and in particular to identify the influence of prior understandings.
   • Students should have opportunities to develop meta-cognitive skills.

b-d) Students should develop an appreciation of different kinds of knowledge. For example:
• Students should have opportunities identify and practise developing practical knowledge-how and propositional knowledge-that.

• Students should develop skills in making valid deductions, both from axioms and from observation statements.

e) Students should develop an appreciation of the differences between rational reconstructions of knowledge and descriptions of actual knowledge development.

f) Students should gain an appreciation of the role and significance of craft-knowledge and tacit knowledge in science. For example:

• Students should have opportunities to develop craft and tacit science knowledge.

g) Students should develop an awareness that science knowledge is characterised as both the body of published knowledge and a state of knowing. For example:

• Students should develop an appreciation of the size and scope of published science knowledge.

• Students should develop metacognitive skills, as a means of developing an awareness of, and a capacity to foster, their own state of knowledge.

Knowledge is related to belief.

h) Students should develop an understanding of the interrelatedness of knowledge and belief. For example:

• Students should have opportunities to identify beliefs about the material world, and challenge (test) them.

i) Students should develop an appreciation of some of the ways in which knowledge is justified. For example:

• Students should have opportunities to analyse justifications of knowledge, such as in contemporary and historical case studies.

j-l) Students should develop an appreciation of internalist and externalist views of knowledge, and the difficulties of extreme versions of either. For example:
Students should have opportunities to analyse knowledge claims, such as in contemporary and historical case studies, for internalist and externalist elements.

*Science is characterised by knowledge as information, facts and data*

**m-n)** Students should develop an appreciation of the nature and role of information, facts or data in science. For example:

- Students should develop skills in collecting and manipulating facts, information and data.
- Students should develop an awareness of, and skills in accessing and using, information, facts and data in a variety of media, such as text books, journals, electronic and print data bases, the Internet, and so forth.
- Students' science knowledge should not be restricted to information, facts and data, but should include reasoned understandings.

**o-q)** Students should develop an appreciation of the nature and scope of the information explosion, and attitudes and skills for addressing it. For example:

- Students should develop and awareness of the scope and rapid rate of growth in science knowledge.
- Students should develop an awareness and some knowledge of cutting edge science knowledge.
- Students should develop an awareness of characterisations of the information explosion as variously beneficent, malevolent and neutral for society, and that each of these characterisations is flawed.
- Students should develop skills in applying multidimensional characterisations of science to critique and analyse the effects of rapid science knowledge growth on society.

*Science knowledge is characterised by being reasoned and having understanding.*

**r-t)** Students should develop an appreciation that science knowledge is partly characterised as a reasoned understanding. For example:
• Students should have opportunities to analyse the reasoning behind a range of fundamental science concepts.

• Students should develop skills in expressing propositional knowledge.

u-v) School Science should provide students with opportunities for students to develop understandings of a range of fundamental science concepts, and their significance. For example:

• Students should develop an appreciation of the nature and purpose of concepts.

• Students should develop understandings for a range of fundamental science concepts.

• Students should develop an appreciation of the often complex character of science concepts and the difficulties this presents those without a science education.

x) Students should develop an appreciation of the ways in which science knowledge could be characterised as 'commonsense', and as non-commonsensical. For example:

• Students should examine commonsense understandings of the material world and test them, either directly or through case studies, for their scientific merits.

y-z) School Science should provide students with opportunities to develop an appreciation of the public understanding of science, the ways in which it is interpreted, and its roles. For example:

• Students should develop an appreciation of ‘folk’ knowledges, their uses and limitations, including their own prior understandings.

• Students should examine case studies of studies of the public understanding of science and its role in disputes and public education campaigns.

Science knowledge is characterised by power and authority
aa-bb) Students should develop an appreciation of the long-standing association between (science) knowledge and power. For example:

- Students should develop an appreciation of how (science) knowledge is commonly associated with power, through its role in 'controlling' Nature; this could be achieved through study of contemporary and historical case studies.
- Students should develop an appreciation of how this association with power lent support historically to claims that western European knowledge is the paradigm for rationality.

cc-dd) School Science should provide students with opportunities to develop an appreciation of the relative merits of (western) science and the natural philosophies of non-western cultures. For example:

- Students should develop a sensitivity to the difficulties in accounting for the successes (power and usefulness) of western science while acknowledging the power and usefulness of other knowledge systems such as indigenous knowledges.
- Students should likewise develop an appreciation of the limits of western science and other knowledge systems.
- Students should develop an appreciation of the effects of using western science as the standard for judging other knowledge systems.

Knowledge as a map of scientific content

ee) School science should provide students with opportunities to develop a knowledge of the content of science.

ff) School Science should provide students with opportunities to develop an appreciation of the historical changes in science knowledge.

gg) School Science should provide students with opportunities to develop an appreciation of the immense scope of science knowledge, and that particular strategies are needed to be able to manage it. (See the information explosion, above, in (o), (p) and (q).)
hh) Students should develop an appreciation that science content can be ‘mapped’ in various ways. For example:

- Students should develop a familiarity with science knowledge as given in the cognitive disciplines or domains of science, and in the body of refereed, scientific publications.
Chapter 12

CONCLUSION

The multidimensional character of science, as interpreted from the literature by the present thesis, is a robust basis for characterising science in the school curriculum.

Introduction

This chapter extends the argument, developed in the preceding chapters and Appendix B, that school Science can and should be grounded in the characterisations of science given in the metascientific literature. This argument is that the rationale for school Science - the justification for its inclusion, nature and scope - is set out in curriculum goals, especially science curriculum goals, and that these goals are legitimated to the extent they reflect the nature of science. True, curriculum goals typically refer to more than just characteristics of individual curriculum subjects: they quite properly concern the education of individual learners and reflect broad social and political goals. However, the inclusion of a particular subject, in this case Science, is justified partly because, among other curriculum goals, it characterises a field called science that is judged to be worthwhile learning. The present thesis argues that this sense of justification increases when we can show that the school subject robustly represents or characterises the field.

To show that it accurately characterises its field, a syllabus must show both that it addresses the variety of views that comprise the field, and that it does so rigorously. The present thesis has shown that there are a variety of scholarly views of science, and argues that its multidimensional analysis is both rigorous and a suitable framework for science curriculum developers. Addressing the variety within the field is best done by seeking the views of practitioners and academic analysts in that field: in this case, scientists, like chemists and biologists, and metascientists, including many scientists but also philosophers, historians and sociologists of science. However, the present thesis has
argued that, while the direct involvement of these groups of stakeholders is necessary, either as curriculum developers or advisers to them, use of the metascientific literature as a resource is also necessary, perhaps more so. It is the literature that gives the current, received state of the field, comprises the considered views of its practitioners and academics, argues the character of science more fully, is open to scholarly critique, and strives to be removed from the anecdotal and situational. To embody diverse views while at the same time claiming to be rigorous, a syllabus must show that it represents the more complex and robust characterisations in the literature rather than the views of particular individuals. Thus the literature can help curriculum developers ensure an appropriate representation of field specialists. Other curriculum stakeholder groups, although not the central concern of the present thesis, make contributions representing broader interests within pluralist societies, and these are mentioned where appropriate.

The present thesis has argued that a robust characterisation must show that school Science is thoroughly grounded in the metascientific literature, and therefore reflects the diversity and rigour of that literature. It argues that this is achieved by a set of six interrelated dimensions of characterisation: knowledge, activity, context, structure, purpose and belief system. In particular, the present chapter draws on section 4 of each of the six companion chapters, that summarise arguments concerning each dimension in the literature and suggest some curriculum implications. The present chapter will not repeat that detail, but instead draws on those arguments to show how the proposed multidimensional characterisation of science applies to some curriculum arguments. It also suggests that its analysis could apply to other, related issues, such as other areas of the curriculum, the curriculum as a whole, selection of an appropriate curriculum model, selection of resources, teacher training, and school organisation; these are speculations and suggestions for further research based on the present analysis.

This chapter is organised as follows.

1) School Science should reflect the nature of science, both in the formally set out curriculum goals that reflect the nature of science and in what is enacted in schools.
2) School Science does not reflect the nature of science as characterised in the metascientific literature, either in its formal goals or as enacted in schools.

3) The multidimensional characterisation developed in the present thesis can inform issues concerning the science curriculum and the nature of science in it.

4) The present thesis has implications for the selection of curriculum models and resources, teacher training and school organisation.

5) The present thesis suggests several areas suitable for further research, and possible tests of its claims.

Sections 1 and 2 consolidate the argument, developed in the thesis to this point, that school Science must ultimately reflect the nature of science, and that a robust characterisation of the nature of school Science must be grounded clearly in the literature that analyses the nature of science. Section 3 shows how the present thesis informs some typical issues that apply to school Science, and the nature of science it promotes. Sections 4 and 5 are more speculative, and suggest some possible implications and areas for further research of the present thesis.
1 School Science should reflect the nature of science, both as formally set out in curriculum goals that reflect the nature of science, and as enacted in schools.

Simply to say that school Science should reflect the nature of science appears to be a truism, yet this leaves important decisions unclarified. What is the nature of science? To what extent should the goals of school Science reflect the nature of science? Who decides these questions? Not only are there a variety of views about the nature of science, there are also a variety of curriculum goals. This section will review some enduring goals of the science curriculum, but will do so by placing them within the context of general curriculum goals that affect the science curriculum but are not always identified in the narrower scope of the science education literature. It will then theorise about some implications of the analysis of the metascientific literature made in the present thesis. We will use as examples analyses of some curricula from pluralist, western democracies, such as the USA, UK and Europe, but with particular emphasis on New South Wales (NSW), Australia, as identified in Chapter 1.

To show that school Science reflects the nature of science, one must show that both the formal, published curriculum goals and the enacted curriculum reflect the nature of science. The former is a statement of intention only, and not of actual practice in schools. The latter alone cannot show that a particular practice is more than happenstance or tradition, rather than a planned curriculum event. Accordingly, this section is structured as follows:

1.1 The metascientific literature characterises the nature of science in multiple, interdependent dimensions;

1.2 The goals of science education should reflect the nature of science;

1.3 The implementation of school Science should reflect the goals of science education; and

1.4 The implementation of school Science should reflect the nature of science.
1.1 *The nature of science is characterised in multiple dimensions*

The present thesis has argued that the metascientific literature characterises the nature of science in multiple dimensions. Further, the present thesis has suggested six dimensions that together account for a selection of summary statements about science, and metascientific arguments: knowledge, activity, structure, purpose, context and belief system. These dimensions are mutually interacting, or interdependent: typically they are used together in the literature and derive the richness of their meaning through these interactions. They were constructed from a semantic analysis of the literature, and consolidated by extensive analysis of it. The six dimensions were constructed in chapters 3 and 4 (the discussions of the methodology and the semantic analysis); consolidated in sections 1 to 3 of the six companion chapters and Appendix B; and summarised in section 4 of the companion chapters.

Discussion in earlier chapters acknowledged that these dimensions are constructed, not absolute, and so may differ from the results of similar attempts by other researchers. It also acknowledged that the metascientific literature is not the only source of views about the nature of science, but used that literature as the source of data because it represents the publicly available, scholarly statements about science. This is consistent with the aim of the present thesis, namely to use current, publicly available, scholarly data to theorise about characterising science for the school curriculum.

1.2 *Science curriculum goals should reflect the nature of science*

It is important that the goals of science education reflect the nature of science because these goals are the formal curriculum statements that provide the rationale for including science in the school curriculum and the formal expression of what school Science should be and include. There have been many arguments put, in a variety of forums since the 18th century, that the field of science should be represented in the school curriculum (DeBoer 1991; Matthews 1994). This is usually interpreted as meaning that there should be study at
school that embodies or characterises what is widely recognised as *science*. That is, the inclusion of *Science* in the school curriculum is justified precisely because it characterises a field regarded by society as worthwhile studying. The study of school Science is justified commonly because it also serves as a vehicle for other curriculum goals, such as the personal and social development of the child; while these are important, they are not central to the present thesis and receive passing mention only.

Science curriculum goals relevant to the present task are found in the science education, general curriculum, and metascientific literatures. Claims that science curriculum goals should reflect the nature of science are made in two ways in these literatures: in the content of science curriculum goals, although this is often implicit, and in explicit calls for school Science to reflect science. Some examples of these claims follow.

### 1.2.1 The content of science education goals as rationales for science in the school curriculum

**Science curriculum goals**

In their review of research into science curriculum goals, Bybee and DeBoer (1994) discerned three main, enduring goals for the science curriculum:

Three major goals have shaped the curriculum and instructional practices in science education. These three goals have been repeated, with continuing variation, through the 200-year history of science education in the United States. Broadly defined, these goals are *understanding of scientific knowledge*, *understanding and using scientific methods*, and *promoting personal-social development*. (Bybee & DeBoer 1994, p. 380; emphases added).

Though identified in the context of the US education system(s), these goals are general and can be identified in the science curricula of other, similar, pluralist western democracies, as we shall see. Bybee and DeBoer also identified some recent initiatives in science curriculum that interest US and other science curriculum developers; we will turn to these shortly. Bybee and DeBoer interpret these three main goals in clusters of goals found in expressions of *what* is to be learned, and, alternatively, in the *ends* or *purposes* of science education.

First are goals that set out *what* is to be learned:

Three such student outcome goals are (1) to acquire scientific knowledge, (2) to learn the processes or methodologies of the sciences, and (3) to understand the applications of science, especially the relationships between science and society.
and science-technology-society. Under this organisation, the students should have some knowledge of the products of science, should have experience with and understand the methods of science, and should understand how science is a force in their world. (Bybee & DeBoer 1994, p. 357)

That is, the familiar goals of knowledge, method and applications are expressed as propositional knowledge and investigative activities. The present thesis interprets this as characterising science mainly by knowledge, activity (processes or methodologies, methods) and context (science and society, in their world).

The alternative source of the three traditional goals arises from the expression of curriculum goals as the ends or purposes of science education:

Another way to view the goals of science teaching is to look at the ends to which the knowledge, method, and applications applies. The goals of science teaching then become (1) personal development, which includes aesthetic appreciation, intellectual development, and career awareness; (2) social efficiency and effectiveness, including the maintenance of a stable social order, economic productivity, and the preparation of citizens who feel comfortable in a technical world and understand issues such as environmental conservation, disease prevention, birth control, industrial development, and computer literacy; (3) the development of science itself, which involves the cultural transmission of scientific knowledge from one generation to the next so that each subsequent generation has a base from which new scientific discoveries can be made; and (4) national security, which includes the development of a strong, technically able military, an internationally competitive workforce, and a citizenry that is sympathetic to the importance of science as a competitive force in this world. (Bybee & DeBoer 1994, p. 358)

This set also can be interpreted in terms of the six dimensions proposed by the present thesis: scientific knowledge, both as the body of science knowledge and the knowledge of the individual; scientific activity, that includes a wider notion of activity than just laboratory work; scientific purposes, as cognitive purposes of science itself, utilitarian purposes of society including government and industry, and personal goals; scientific structures, such as scientific institutions and knowledge structures; context, including social, military and citizen applications, career development; and belief system, which is largely implied, but attitudes such as feel comfortable with, aesthetic appreciation and sympathetic suggest an alignment between the belief systems of students and science.

As an example of such a goal set, the Canadian report, Science for Every Citizen, includes these traditional goals in a statement that also indicates the shifts in priorities for education from the 1980s:
i. Develop citizens able to participate fully in political and social choices facing a technological society.
ii. Train those with special interest in science and technology education for further study.
iii. Provide an appropriate preparation for modern fields of work.
iv. Stimulate intellectual and moral growth of students.

(Fensham 1992, p. 797)

Fensham notes that the two target groups - 'a scientifically based work force and a scientifically literate citizenry' - are covered in goals 1 and 2, the third accommodates the impact of technological development on the structure of work and the economy, and the fourth links individual qualities to the 'corporate actions referred to in the first objective' (1992, p. 797). We will return to each of these throughout this chapter.

General curriculum goals

General curriculum goals are also a source of rationales for including science in the school curriculum. There is a range of general curriculum goals identified in the curriculum literature that influence the deliberations of science curriculum developers, although they may be inexplicit to some stakeholders. This range reflects both the multiple purposes of the school curriculum and different theoretical and ideological perspectives. For example, the 1992 Handbook of Research on Curriculum (Jackson (ed.) 1992), a project of the American Educational Research Association, included chapters on Conceptions of Curriculum and Curriculum Specialists (Jackson), Curriculum Policy (Elmore & Sykes), The Relationship between Culture and Curriculum (Peshkin), Conceptions of Knowledge (Schrag), Curriculum Ideologies (Eisner), Organisation of the Curriculum (Goodlad & Su), besides sections on the Curriculum as a Shaping Force and Topics and Issues Within Curricular Categories (the latter including a chapter on Science and Technology by Fensham). Each of these implies or states goals for the curriculum, showing how different visions and models of curriculum arise from different analytical perspectives, and even further variation arising from different theoretical positions within an analytical perspective.

To varying extents and in different ways, these goals influence the nature of school Science. An example is the cluster of goals for acquiring knowledge, a central goal in most curriculum writings, and probably the most enduring:
The oldest, mainstream tradition regards curriculum as worthwhile knowledge and focuses on what knowledge is of most worth within a society, in order to set the criteria and grounds for developing a curriculum. The touchstones may be an intellectual heritage, or the characteristics of learners, or scientifically validated knowledge, or a conception of a good society, and the policy-related aim is to provide authoritative prescriptions for curriculum content that express the underlying orientation. (Elmore & Sykes 1992, p. 195)

Thus the term *worthwhile knowledge* is an umbrella for different notions of what is valued as worthy of study, found, for example, in the literatures on curriculum policy, ideology and organisation.

Reviews of these curriculum fields, from Elmore and Sykes, Eisner, and Goodlad and Su, above, show that different curriculum views judge knowledge to be worthwhile acquiring when it:

- is part of being an educated person, resulting from study of the liberal arts, including the discipline *science*;
- characterises the discipline *science*;
- is appropriate to the cognitive development of students;
- empowers students to be participatory citizens in a pluralistic democracy;
- helps students realise their individual potentials;
- comprises the multiple dimensions of intelligence, and so enables students to make meaning of the various systems of symbols used in society;
- improves the efficiency of instruction;
- contributes to the economic and social prosperity and security of the society;
- engenders beliefs in a religious orthodoxy;
- contributes to the ability to think rationally; and
- is useful in understanding, shaping and resolving social issues.

As a set, these interpretations are much more consistent with the multidimensional character of science identified in the present thesis, than with the essentially internalist and positivist character of most traditional school Science. This is so even where some knowledge judged to be worthwhile, such as the empowering or religious examples, is judged to be beyond the scope of, or even in conflict with, accepted scientific knowledge. Quite aside from non-science knowledge having roles and places elsewhere in the school curriculum, a multi-

dimensional school Science will show that science is complex and is a resource, along with social, legal, ethical and other spheres of knowledge, in understanding humans and phenomena of the material world.

On these grounds it is reasonable to claim that in the cluster of curriculum goals concerning worthwhile knowledge, most support a robust treatment of the nature of science, and all the more so if several goals are included together. While it is true that judgements of worthiness arise from complexes of curriculum goals, and the criteria for judging worthiness will vary according to curriculum goals, science knowledge is widely agreed to be worthwhile. A multidimensional character of science, such as argued by the present thesis, fits a variety of curriculum goals concerning worthwhile knowledge.

The different notions of worthiness of knowledge point to a need for different curriculum stakeholders to clarify what is central and worthwhile in their views of the curriculum and constructing rationales for these views. Thus the notion of **worthwhile knowledge** applies to the science curriculum in various ways. It is reasonable to claim that most school curricula, and certainly those addressed by the present thesis, value science knowledge as worthwhile. The three traditional science curriculum goals mentioned above represent three views of what is worthwhile. To the extent they classify knowledge, they represent respectively: the canonical or received knowledge of the discipline, which can be characterised as propositional knowledge-that; knowledge of problem-solving and investigation, including knowledge-how; and knowledge of applications.

1.2.2 Other calls for school Science to reflect the nature of science

Besides the content of actual curriculum goals, other support for science curriculum goals is given in analyses of and theorising about science curriculum goals, by the education, science and metascience communities.
From a science education perspective, DeBoer (1991, pp. 215ff) has described several main goals of science education from its (mainly US) history, and their direct relationship to the nature of science desired in schools. These goals include:

- the mental discipline developed in students by science studies;
- enculturation in science as a significant part of contemporary western culture;
- the development of significant social and personal outcomes;
- the development of economic well-being, national security and international prestige; and
- a better understanding of the physical world.

These, of course, are not mutually exclusive, even though particular curriculum initiatives tended to emphasise only one or two each.

A second example is Matthews (1994), who in reviewing historical debates about the science curriculum, discerned three main curriculum emphases in US science curricula:

There have been three competing traditions in US science education up to the present time: theoretical, stressing the structure of the disciplines; applied, stressing the science and workings of everyday things; liberal or contextual, stressing the historical development and cultural implications of science. None of these traditions have, of course, been exclusive. (Matthews 1994, p. 13; emphases added)

A third example is Roberts (1982; 1988), who has argued that there have been different curriculum emphases in twentieth century US science curricula, and they entail different views of science as well as of learners, teachers and society. Roberts describes seven such emphases, acknowledging that choosing seven rather than six or eight involves a judgement. Further, Roberts argues that the actual number is insignificant compared to the concept of multiple emphases, and that the seven represent emphases that have been tried, rather than what might be possible. The seven are as follows.

(i) Everyday Coping emphasises the importance of science 'for understanding and controlling one's environment - be it natural or technological':

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1 Roberts' analysis is in this respect similar to that used by the present thesis in constructing its six dimensions of characterisation.
What is being valued is an individual and collective understanding of scientific principles, as a means for coping with individual and collective ‘problems’. The student must apply, indeed must learn how to apply, the principles and generalisations learned in the science classroom, if the message is to get through. (Roberts 1982, p. 246; emphasis in original)

This approach characterises science knowledge not just as the body of received knowledge—that, but as personal knowledge—that and knowledge-how. It also takes science activity to include general problem-solving and information-acquisition skills, rather than just laboratory investigation activities, and entails understandings of science in social and other contexts, scientific purpose and scientific belief systems. Roberts notes that this emphasis has been re-articulated several times this century and is an essentially optimistic rather than realistic view; by implication, while its optimism no doubt contributed to its recurrent popularity, its lack of realism may have contributed to its lack of sustained and widespread implementation.

(ii) *Structure of Science* emphasises ‘how science functions intellectually in its own growth and development [such as] the interplay of evidence and theory, the adequacy of a particular model for explaining phenomena at hand ..., the changing and self-correcting nature of scientific knowledge, the influence of an investigator’s “conceptual principles” on the kind of theory developed, etc.’ (Roberts 1982, p. 247). This may be interpreted as emphasising the interplay of science knowledge, structure and belief system in characterising science.

(iii) *Science, Technology, and Decisions* emphasises ‘the limits of science in coping with practical affairs’ such as distinguishing the boundaries between science and technology, political decisions and personal decisions (Roberts 1982, p. 247). This is somewhat the reverse of the Everyday Coping emphasis, and draws particularly upon the dimensions context, purpose and activity.

(iv) *Scientific Skill Development* emphasises ‘competence in the use of processes that are basic to all science’ (Roberts 1982, p. 247). Notwithstanding the usefulness of generic problem-solving and investigative skills, the present thesis interprets this emphasis as a characterisation not just limited to science activity, but limited in its characterisation of science activity. Roberts argues, and I think correctly, that such a view communicates to the
student the message that 'skilful use of means (scientific process) will automatically yield … a correct end (product)' (Roberts 1982, p. 247), a message at odds with the understanding of science activity argued in the present thesis.

(v) Correct Explanations emphasises the body of science knowledge-that, as accepted or received by the science community. This is roughly the reverse of the emphasis on process, rather than knowledge-that, in Scientific Skill Development:

This is the familiar 'master now, question later' emphasis in science education. Ziman (1968) put it thus. "The job of the ordinary science teacher … is to make all plain, and plausible, to encourage the student to entrust himself [sic] freely to basic theory. To express doubts, to utter warnings, at this stage will inhibit the confident use of the new technique, the new language" (p. 71). (Roberts 1982, p. 248)

Roberts noted (p. 248) that this emphasis is also a message 'about the authority of a group of experts to determine the correctness of ideas', a view at odds with a robust understanding of context as a characteristic of science. The present thesis interprets this emphasis as characterising science by limited notions of science knowledge and context.

(vi) Self as Explainer emphasises the cultural and historic contexts of science, with the goal of students appreciating science as an expression of human capability and therefore of their own humanity:

The story [of science] is a long and interesting one, but to simply call it 'history of science' is likely to mislead; probably the most common image of history of science is the dry catalogue of who-did-what-when. To animate the history of science is to examine growth and change in scientific ideas as a function of human purpose, and of the intellectual and cultural preoccupations of the particular settings in which the ideas were developed and refined. Other systematic (though nonscientific) ways to explain events - e.g., religious, magical - can readily be seen in a similar light, especially with regard to explanatory purpose (Roberts 1970). Then one has something other than 'ignorance' with which science can be compared.

The student thus gets the message that the humanity of science is his [sic] own humanity. For he, too, is an explainer of events, with his own purposes, his own place in a matrix of intellectual and cultural preoccupations. (Roberts 1982, p. 248)

This emphasis characterises science multidimensionally, as a combination of public and personal knowledges, activities that develop and refine ideas, explanatory and other

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2 Some may argue that the apparent complexity of the present thesis shows that we do have to rely on experts, in an informed way, in the end. This thesis does argue that a range of authorities should be involved. Also, the complexity of the argument supporting a multidimensional characterisation should not be confused with the actual characterisation, which involves just six dimensions as a means of clarifying the range of characteristics for science educators and students.
purposes, scientific and non-scientific belief systems and purposes, and historical, cultural and intellectual contexts.

(vii) Solid Foundation emphasises the goal of science education as preparation for future science education, a view that Roberts sees as emphasising the vast and complex character of science but ignoring ultimate curriculum goals. One could add that it also has little to say about the character of science itself.

Roberts later summarised the views of science entailed in each of these emphases:

Everyday coping:
A meaning system necessary for understanding and therefore controlling everyday objects and events.

Structure of science:
A conceptual system for explaining naturally occurring objects and events, which is cumulative and self-correcting.

Science, technology, decisions:
An expression of the wish to control the environment and ourselves, intimately related to technology and increasingly related to very significant social issues.

Scientific skill development:
The outcome of correct usage of certain physical and conceptual processes.

Correct explanations:
The best meaning system ever developed for getting at the truth about natural objects and events.

Self as explainer:
A conceptual system whose development is influenced by the ideas of the times, the conceptual principles used, and the personal intent to explain.

Solid foundation:
A vast and complex meaning system which takes many years to master.

(from Roberts 1988, p. 45, Table 1)

These emphases derive from different conceptions of the nature of science, alongside goals concerning the learner and society. While individually, most of these emphases make limited characterisations of science, as a set they present a robust, multidimensional characterisation that is broadly consistent with that argued by the present thesis. This was recognised by Fensham, who when discussing Roberts’ theory (Fensham 1994), suggested applying different curriculum emphases in different years from K-12; that is, progressively developing Roberts’ set of emphases.

Roberts’ theory of science curriculum emphases supports and is supported by the present thesis. It supports this thesis in that it provides a means of addressing the multidimensional character of science in such a way that more complex issues are dealt with progressively and after preparatory matters have been covered. Of particular importance to the present thesis, Roberts’ notion of curriculum emphases goes beyond discerning different
emphases to show they embody and promote particular and different characterisations of science. That is, calls for curricula to embody particular emphases are perforce calls to embrace particular characterisations of science. Roberts' theory is supported by the present thesis in two ways. First, the dimensions of characterisation presented in the present thesis enable these differences in characterisation to be clarified, and compared with each other and the metascientific literature. Secondly, Roberts' emphases need an argument to support Fensham's contention that a range of emphases should be presented: the idea of presenting the range may seem appealing, but it needs more substantial support than just this feeling. The present thesis provides that argument: that no single emphasis necessarily entails a robust, multidimensional characterisation, but the set of emphases does.

**Calls from the scientific and metascientific literatures for school Science to reflect the nature of science**

The metascientific and scientific communities and their literatures also call for school Science to reflect the nature of science, and for particular views of science, in the curriculum. Perhaps the clearest example of the role of the scientific community in the school Science curriculum is the US, in its response to Soviet science achievement during the Cold War:

[The 1957 launch of the Soviet satellite] *Sputnik* brought the claims of reformers of science education into national prominence. The launch triggered a flurry of legislation, the principal being the 1957 National Defense [sic] Education Act, which gave $94 million for science education in three years from 1958 to 1961, and a further $600 million in the years from 1961 to 1975. Conferences and meetings occurred across the country [such as the 1958] Yale conference sponsored by the President's Committee on Scientists and Engineers (Elbers & Duncan 1959).

The National Science Foundation was instrumental in the transformation of school science into proto-university science, a process sometimes called the professionalisation of school science. The NSF's first school curriculum grant was for $1,725 in 1954; its 1956 grant to PSSC was $300,000. The [1957] National Defense Act transformed this meagre level of funding, and subsequently transformed US science education. In 1957 the NSF said that its curriculum projects:

- seek to respond to the concern, often expressed by scientists and educators, over failure of instructional programs in primary and secondary schools to arouse motivating interest in, and understanding of, the scientific disciplines. General agreement prevails that much of the science taught in schools today does not reflect the current state of knowledge nor does it necessarily represent the best possible choice of materials for instructional purposes. (Crane 1976, pp. 56-7)
The NSF put scientists firmly in the saddle of curriculum reform, teachers were at best stable hands, and education faculty rarely got as far as the stable door. The PSSC project epitomised ‘top-down’ curriculum development; its maxim was “Make physics teacher-proof”. In a 1962 explanation of its policies, the NSF said that:
Projects are directed by college-level scientists, and grants are made to institutions of higher learning and professional scientific societies. Emphasis is placed on subject matter rather than pedagogy. (Klopfer & Champagne 1990, p. 139)
(Matthews 1994, pp. 16-17)

This significant increase in support from the science community and the government, as stakeholders, led to a large number of high-profile curriculum projects:

The NSF supported the explosion of ‘alphabet curricula’ in the late 1950s and early 1960s. The first curriculum to be widely used was that of the MIT’s Physical Sciences Study Committee (PSSC). Then followed the Chemical Bond Approach (CBA), Biological Sciences Curriculum Study (BSCS), Chemical Educational Materials (CHEMS), Earth Science Curriculum Project (ESCP), Introductory Physical Science (IPS), Project Physics and a host of others. By 1975 the NSF supported twenty-eight science curriculum reform projects. A number of these were directed at the elementary school: Elementary Science Study (ESS), Science Curriculum Improvement Study (SCIS) and Science - A Process Approach (SAPA). (Matthews 1994, p. 17)

Most of these emphasised what Roberts called the correct explanations approach, being acontextual or internalist depending on one’s metascientific perspective. However, a few attempted a more contextual approach, broadly a self as explainer emphasis, such as Harvard Project Physics, the yellow version of the BSCS High School Biology, and the smaller-scale Klopfer and Cooley Use of Case histories in the Development of Student Understanding of Science and Scientists. In 1976-77 it was estimated that about nineteen million students, or forty three per cent of the student population, were using NSF-supported science curricula. This is a significant proportion considering the large number of often fiercely independent US school districts that make the decisions about curriculum models, texts and so forth.

In Australia, the far smaller number of state-based school systems prescribe syllabuses but not texts or curriculum models. Also, with the possible exception of the Australian Academy of Science (AAS), there is no central, scientific community/government stakeholder with significant power and discretionary funding, like the NSF in the US. Australian science organisations such as the Australian and New Zealand Association for the Advancement of Science (ANZAAS), Commonwealth Scientific and
Industrial Research Organisation (CSIRO) and the Australian Nuclear Science and Technology Organisation (ANSTO) have a markedly lower profile in school Science than comparable US organisations like the NSF and the AAAS. Nonetheless, the absence in the early 1960s of a contemporary school Science text was met in NSW with a text produced by a team of scientists and science educators: the ubiquitous, blue ‘Messel’ text (Messel 1964), a product of the Nuclear Research Foundation within the University of Sydney, with the co-operation of the NSW Department of Education, the largest school system in NSW. This also was a discipline-based, correct explanations emphasis, with chapters based on major concepts of physics, chemistry, biology and geology. In both the US and Australian examples, science tended to be characterised as an inductivist process.

Evaluations of these approaches showed some successes:

Paul Hurd (1970) summarised what were generally perceived to be the major strengths and weaknesses of the new courses. He listed the strengths under 14 specific points, the heart of which can be summarised in the following statements:

1. The new curriculum projects contained information that was more up to date and had more scientific validity than the older courses.
2. The new courses engaged students in independent, ‘discovery’-type investigations, which were considered to be more characteristic of the scientific enterprise and which were believed to lead to more meaningful learning.
3. The new courses presented a more accurate picture of the nature of science by ‘stressing its nonauthoritarianism, its intuitiveness, its incertitude, its questions and doubts, its motivations, its dependence upon human qualities, its processes of inquiry, and its unifying principles’ (p. 95).
4. The new course were less concerned with ‘subject coverage’ and dealt instead with a smaller number of ‘significant concepts’, taught in depth and in context until the student has some intuitive feeling for the topic’ (p. 95).

DeBoer judged these curriculum approaches as significant and unprecedented:

The courses achieved the sought-after rigour, and they presented the disciplines of science in a more thorough and honest way. They presented the science disciplines as logically structured areas of human investigation, they dealt candidly with the nature of scientific research, and they encouraged students to think and act like scientists within the structure that was established. (DeBoer 1991, p. 171)

As with other sources of curriculum goals, they also had shortcomings. We will address the shortcomings in section 2 below, where we will also critique assumptions, by DeBoer and others, about the nature of science and school Science.

1.3 The implementation of school Science should reflect the goals of science education
While it is necessary that the goals of science education should reflect the nature of science, it is not sufficient: the practice or implementation of school Science should do likewise. This statement is implicit in curriculum goals, which otherwise would be empty. More than this, it is logically necessary in order to conclude that the implementation of school Science should reflect the nature of science: the goals (the intention) must reflect the nature of science, and the implementation (the practice) of science education must reflect the goals so that school Science reflects the nature of science.

1.4 The implementation of school Science should reflect the nature of science

Taken together, sections 1.1, 1.2 and 1.3 above comprise an argument that the practice of school Science should reflect the multidimensional nature of science. We will turn now in section (2) to examine critiques of the goals and practice of science education to argue that the practice of school Science does not reflect the nature of the field, science, especially a robust, multidimensional characterisation of science.
School Science does not reflect the nature of science as characterised in the metascientific literature, either in its formal goals or its enactment in schools.

Having set out the case for school Science reflecting a multidimensional characterisation of science, we turn now to appraise the nature of science in the school curriculum. Following from section (1), this appraisal will address both the formal goals of science education and the enacted school curriculum. In brief, the conclusion is that both the formal and enacted science curriculum poorly characterise science, leading to doubts about the rationale for including school Science as a mandatory component of the curriculum.

*School Science as unproblematic and problematic*

A note of caution should be sounded here, that given a topic like school Science, with so many goals, interpretations and stakeholders, it is possible to find fault with almost any aspect of it. This argument has been well put by Eisner (1992) in his review of research on curriculum ideologies. There he characterised curriculum subjects as *problematic* or not, depending on whether they are considered to be central to the curriculum, like science, or marginal, like anthropology. This arises from ideological concerns, and applies directly to issues such as the nature and purpose of science in the school curriculum. The problematic character of certain subjects arises from particular curriculum ideologies, and applies in two ways:

First, what is considered to be a given or believed to be axiomatic in education enjoys a kind of security that is seldom threatened by marginalisation: there are few people today for whom the development of literacy is a questionable aim of schooling. In this sense, this particular aim is nonproblematic. How it ought to be taught is another matter, but that it ought to be achieved is not. In contrast, whether subjects like the arts or courses in the psychology of child development should be an important part of the curriculum is another question ...

Second, when a curriculum ideology emphasises the importance of a particular subject, that subject ineluctably becomes problematic. By 'problematic' here I mean that since decisions about the best ways of achieving the aims of highly valued fields are almost always less than optimal, student performance in the subject is typically a source of discontent and, in this sense, problematic. The problematic character of the most valued subjects makes them continuous objects of attention, whereas those subjects that are marginalised or neglected altogether never achieve a problematic status. (Eisner 1992, pp. 302-3)
Thus, in the first sense, science is not problematic, in that there is general agreement that science should be included in the school curriculum, and usually has the status of a core subject, mandatory for all students, at least until the senior secondary years. In the New South Wales curriculum, for example, study of science is mandatory for years K-10, and remains part of most students' selection in the senior secondary (11-12) years. Thus the McGaw Report, mentioned in Appendix B.6, provided data only on English, Mathematics and Science to show how HSC scores vary according to gender and geographic differences. In this sense, science is less problematic than, say, sex education classes, which require parental endorsement in state schools, or Scripture classes, which are non-compulsory in state schools and receive varying emphases in non-government schools according to variations in ideologies.

However, science is problematic in the second sense of Eisner's use: science, in the curricula addressed by the present thesis, is highly valued and therefore, as Eisner points out, is subject to high expectations and high levels of scrutiny. Of course, education generally, not just at school level, has come under increasing public and political scrutiny in the 1980s and 1990s, as we have noted, but science education, particularly school Science education, like literacy and numeracy, is a common focus for this attention:

In the 1980s, more than 300 [US] reports called for a reform of education. There is no precedent in history for such widespread reform efforts in education. These reports made fairly consistent recommendations for improving science education. The particular goals and implied curriculum varied with the group making the recommendations. [Of particular note among the reports influencing reform of US science education are] the American Association for the Advancement of Science (AAAS) report *Science for All Americans* (1989), the NSTA project *Scope, Sequence, and Coordination* (Aldridge 1989, 1992), and the National Center [sic] for Improving Science Education (NCISE) reports on middle-level education (Bybee et al., 1990) and secondary education (Champagne et al., 1991). (Bybee & DeBoer 1994, p. 382)

Briefly, their goals are: social scientific literacy, in *Science for All Americans*; improved learning of the canonical knowledge of science disciplines, by the reorganisation of scientific knowledge, in *Scope, Sequence, and Coordination*; and a blend of knowledge acquisition and personal and social improvement through coordinated development of local school Science programs, in the NCISE reports (Bybee & DeBoer 1994, pp. 382-4).
In Australia, there has not been the same attempt at science curriculum reform based on high profile and broadly influential reports, but nonetheless science is problematic in the second sense of Eisner’s term. For example, in the early 1990s there was an attempt to nationally coordinate the complete school-level curriculum from K-12, resulting in national profiles for each subject, including Science, intended as frameworks or guides for curriculum development by each of the state systems. The mathematics and science profiles in particular attracted considerable criticism from bodies representing academic disciplines, such as the Australian Institute of Physics, and the print media for their lack of rigour and undue emphasis on social factors (for example, *The Age* editorial of 31 May 1993, ‘A Failed Curriculum’; Bolt’s article, ‘Science Gone Mad’ in the *Herald Sun* of 10 June 1993; and the *Public Statement on the Draft National Statement and Profile for Science*, Australian Academy of Science, 1993). It also came under attack because of the concentration of interest on received knowledge at the expense of the more student-centred approaches to science education developed in the 1970s and 1980s (Fensham 1995). The eventual effect of this dispute has been mixed and, at the time of writing, unresolved. It was the unresolved nature of this and other, related issues, that prompted the writing of the present thesis, which argues that such issues are resolvable to a greater degree of consensus than before, through better informed and clarified discussion. Criticisms of the rigour of the science curriculum are discussed in section 3.1 below.

*The argument that school Science does not reflect the nature of science, and that its justification may therefore be compromised*

Taking into account the caution, above, that critiques of school Science may be a function of school Science being problematic in the second of Eisner’s senses, this section is set out as follows:

2.1 The goals of science education do not reflect the nature of science;

2.2 The practice of school Science does not reflect the nature of science;

2.3 The practice of school Science does not reflect the goals of science education.

2.4 Therefore school Science does not reflect the nature of science.
2.5 Therefore these shortcomings compromise the justification for science being in the school curriculum.

2.1 The goals of science education do not reflect the nature of science

There are compelling arguments that the goals of science education do not reflect the nature of science. These are based on analyses of both science curriculum goals and general curriculum goals.

2.1.1 Science curriculum goals

We noted above a range of science curriculum goals and emphases that entailed various views of the nature of science. While rationales for school Science draw on a range of science curriculum goals, of which characterising the nature of science is but one, criticisms of school Science frequently cite the poor representation of science in schools as a significant failing:

It has long been recognised that science education for the purpose of general cultural development has been one of the primary roles of the secondary schools. As evidenced by student enrolments, however, our ability to translate this recognised responsibility into effective programs is another issue. Responding to this failing, Helgeson and colleagues (1978) stated:

A review of state requirements, ... course enrolments from state and national reports, and current reports of various groups regarding educational needs indicate science courses are usually required in only one or two years of the four year high school program. In the opinion of the reviewers, it appears that the role of science in the secondary school curriculum for general education remains unclear. What students should learn also remains unclear. (p. 37)

Perhaps the primary reason that the role of science remains unclear is that there are so many valid and often competing justifications for science in the curriculum. These justifications for teaching science affect what kind of science is taught and the ways in which it is taught. (DeBoer 1991, pp. 215-6; emphasis added)

The present thesis has shown at some length that there are many different views of science, each of which characterise science in multiple dimensions. Applying this argument to the three enduring science education goals identified by Bybee and DeBoer, above, and to the various science curriculum emphases above identified by Roberts, above, suggests that they selectively characterise science. That is, they characterise science incompletely because they selectively or incompletely draw on the multiple dimensions of characterisation.
DeBoer, in the passage above, is correct in observing that there are so many valid and often competing justifications for science in the curriculum. The present thesis argues that the reason for this is the selective appeal to the nature of science. Each is valid because it appeals to particular characteristics, or at least elements of dimensions, but appears to conflict with other, reasonable justifications because they make similarly selective appeals to other dimensions or elements of dimensions. Thus the source of conflict is the use of different, selective characterisations, rather than any view being necessarily ‘right’ or ‘wrong’.

Indeed, in the present absence of any systematic, multidimensional analysis of different goals and emphases, arguments about the inherent correctness or incorrectness of a characterisation of science in these broadly accepted goals and emphases would be difficult to sustain. (i) Thus, the goal of acquiring scientific knowledge is widely interpreted as an internalist view of science knowledge-that. It represents not only an inadequate characterisation of science knowledge but also an inadequate representation of the multidimensional character of science. That is, it neglects to show that science is also characterised by other dimensions, and that science knowledge is defined by its necessary combination with these other dimensions: purpose, activity, context, structure and belief system. (ii) Similarly, the goal of learning the processes and methodologies of the sciences neglects the role of purpose, context, belief system, structure and knowledge in characterising scientific activities, that scientific processes and methodologies are variously interpreted, and that scientific activities are more than just processes and methodologies. (iii) Understanding the applications of science may lend itself more easily than the first two goals to a multidimensional characterisation of science, because it entails those goals and lends itself easily to broader issues that entail other dimensions. However, this is not a necessary outcome. It is possible that some overarching goal, concerning understanding the multidimensional character of science, would entail at least the first two enduring goals and lend itself well to the third.

A similar argument can be made for Roberts’ curriculum emphases. Of these, the self as explainer and solid foundation emphases probably lend themselves most readily to a
robust, multidimensional characterisation of science. Both draw clearly on both the received and personal senses of science knowledge, context, purpose, activity, structure and belief system. Still, a multidimensional characterisation is not a necessary outcome, nor are specific elements of each dimension. The potential of the solid foundation emphasis is clouded by its traditional use to justify proto-university, internalist characterisations of science. The potential weaknesses of the other emphases are reasonably evident: everyday coping may not attend to institutional science or to whole clusters of concepts that do not arise in the everyday life of students; structure of science may only attend to the intellectual contexts of science; science, technology and decisions may attend to boundary issues at the expense of the accepted corpus of knowledge, and to broader rather than individual contexts; scientific skills development has been broadly criticised in recent years for its undue emphasis on process at the expense of received knowledge, but we also noted above that it can imply a deterministic view of science; and we have mentioned already in several places widespread post-positivist criticisms of the traditional emphasis on correct explanations.

2.1.2 General curriculum goals

General curriculum goals also affect the nature of school Science, because while they are not routinely addressed by the science education or metascientific literatures, they nonetheless apply to Science as a component of the general curriculum. General curriculum goals have a broader scope than just science, because they reflect the aspirations of all curriculum stakeholders. Therefore, as a set but not in every instance, they do not necessarily entail a robust characterisation of science in the school curriculum. They arise from many sources, of which we will mention three: policy, ideology and structure.

Policy as a source of curriculum goals

Some curriculum goals arise from educational and public sector policy, where curriculum policy is defined as ‘the formal body of law and regulation that pertains to what should be taught in schools’ (Elmore & Sykes 1992, p. 186). A major finding of recent
research on curriculum policy is an increasing government presence in curriculum policy, which Elmore and Sykes have interpreted in two ways: the curriculum as an instrument of public policy (public policy perspectives on curriculum), and policy as an influence on curriculum (curriculum perspectives on public policy) (Elmore & Sykes 1992, p. 185).

Where the curriculum is interpreted as an instrument of public policy, there is a distinction between policy as a statement of intent and policy as a statement of action. The present thesis theorises about statements of intent, but in principle it applies both to policy as intent (goals) and action (implementation). The public policy literature interprets statements of policy intention variously, as: statements with uncertain consequences; reflecting multiple forms of authority; symbolic rather than instrumental actions; and as ideologies for organising authority.

Where policy is interpreted as an influence on curriculum, there are different policy traditions which are either goals or sources of goals. Elmore and Sykes discussed two such goal clusters that are explicitly and commonly addressed in formal curriculum statements: (i) worthwhile knowledge and (ii) societal goals like change, efficiency and consensus (a rational system). Goal clusters can also be more critical perspectives identified by curriculum scholars as implicit in broader, socio-political policies, and not explicitly stated in curriculum documents. Thus (iii) curriculum as control interprets the curriculum goals as either responding to pressing social changes, by incremental changes to education practice, or expressing the dominant interests of society. The rise of the curriculum as a rational system in the 1980s and 1990s reflects societal/political interest in school Science serving national interests, as we will discuss. (iv) Where the curriculum is interpreted as capital, the curriculum as an economic commodity transacted with other cultural entities within the market:

The curriculum-as-capital perspective examines the relationship among [curriculum] benefits [such as certificates, diplomas and licences] and the principles that regulate their distribution. Analysis in this mode tends to reverse fundamental assumptions about curriculum and its effects. The educational assumption is that the character of the curriculum affects society and the economy through the knowledge and skills conveyed to workers and citizens. The economic perspective proposed by the curriculum-as-capital theorists, however, regards the interaction between the educational, economic and social systems as affecting the character of the
curriculum, and this reverse perspective sheds new light on curriculum policy. (Elmore & Sykes 1992, p. 207)

Thus this view diminishes the value of studying science for its own sake or for individual enrichment, for example. Ruby (1991) has argued that national (Australian) concern with national economic competitiveness has become a criterion for judging the appropriateness of curriculum goals and the effectiveness of the curriculum. To extend that argument, framing curriculum goals in terms of national interest devalues and probably obscures other curriculum goals that may better serve national interests in the longer term. The better justification is to include goals concerning the national interest along with traditional science education goals such as personal and social development and the acquisition of worthwhile knowledge. The complex, multifaceted nature of curriculum theories is well served by a multidimensional characterisation of science.

**Ideology as a source of curriculum goals**

Another source of curriculum goals is ideology, where curriculum ideology is taken to be the 'value matrix' used to justify the direction of the curriculum:

Curriculum ideologies are defined [here] as beliefs about what schools should teach, for what ends, and for what reasons. Insofar as an ideology can be tacit rather than explicit, it is fair to say that all schools have at least one ideology that provides direction to their functions. Ideologies are belief systems that provide the value premises from which decisions about practical educational matters are made. (Eisner 1992, p. 302)

Educational ideologies also apply to the science curriculum. Educational ideologies, like science ideologies, form part of belief systems: like Eisner, the present thesis argues that it is belief systems that act as ideologies, and not just for science but for curriculum and other endeavours also3. Also, it should be unsurprising that there is overlap between the goals identified by studies in ideology and those identified in policy studies, considering the overlap between policy and ideology. A recurring theme in policy studies 'is how policies act as ideologies for organising and rationalising authority in political systems' (Elmore & Sykes 1992, p. 211).

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3 We will pursue this line of thinking towards the end of the present chapter when speculating about how the present thesis applies to areas of the curriculum other than science, and to the curriculum as a whole.
Eisner suggests six ideologies as representing the spread within the curriculum literature, from which we identify the following goal clusters: (i) to 'shape the views of others so that they match the views of those who have already discovered the truth contained in the orthodoxy' \(\text{(religious orthodoxy)}\) (Eisner 1992, p. 307); (ii) the development of human reason, or rationality \(\text{(rational humanism)}\); (iii) the development of intelligence, and social reform, through the intellectual development of the individual child \(\text{(progressivism)}\); (iv) the ‘critical understanding, critical evaluation, and informed commitment to the improvement of society’ \(\text{(Kemmis, Cole & Suggett 1983 p. 15)}\); (v) the development of students as individual learners and emancipated or empowered citizens; and (vi) to develop ‘the ability to represent or recover meaning in the various forms in which it can be experienced’, the quest for meaning being a basic part of human nature \(\text{(cognitive pluralism)}\) (Eisner 1992, p. 318). At the time of writing, however, none of these is as dominant at Australian policy levels as ideologies of efficiency, accountability and national benefit, as identified by Ruby (1991) and Sharpe (1991). Further, none necessarily entails a robust characterisation of science.\(^4\)

**Structure as a source of curriculum goals**

A third source of curriculum goals that apply to the science curriculum is the structure or organisation of the curriculum. Goodlad and Su (1992) have argued that organisational structures bear directly on the definition and expression of a range of curriculum goals:

The primary purposes of seeking alternative ways to organise the curriculum are to increase human accessibility to knowledge and ways of knowing, and to foster understanding. The perspective one brings to the task is heavily influenced by one's conception of knowledge, however well or ill formed. Ideally, the way the curriculum is organised should enhance students' effectiveness as citizens, workers, parents, and participants in the whole of life - their ability to take part in the human conversation (Oakeshott 1962). Curriculum organisation is intended to render knowledge in such way that it is readily accessible to large numbers of people (Cremin 1971). (Goodlad & Su 1992, p. 328).

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\(^4\) Eisner notes that it is preferable to speak of **ideologies** rather than a single **ideology**, considering 'that there is no single ideology that directs education' (Eisner 1992, p. 302), and we find proliferating values in pluralist societies such as the US and Australia. Thus we can identify differing ideologies between school systems, or even between individual schools, but even within a single system or school we can identify different ideologies, in the sense that ideologies vary from those expressly given in mission statements or public policy documents to the tacit decisions made by schools and individual teachers.
Goodlad and Su do not suggest that the goal of a curriculum is its own structure; this is nonsensical. Rather, different curriculum structures entail and enable different curriculum goals: (i) to structure school learning around traditional, enduring disciplines, where each has 'a presumed logical organisation' (subject disciplines) (Goodlad & Su 1992, p. 335); to foster student interest and development by using them as the structural basis; (iii) to organise the curriculum so that students are able to appreciate the significant issues that affect people and their societies (major social issues); and (iv) in practice, some hybrids of these three. However, none of these entails a robust characterisation of science.

Knowledge as a central and enduring curriculum goal

We noted in section 1.2.1, above, that the acquisition of knowledge is an enduring and significant - even central - curriculum tradition, whose characteristic goal, worthwhile knowledge, has been interpreted variously, as: the tradition of the liberal arts; cognitive-developmental approaches to learning; efforts to improve the efficiency of instruction; social reconstruction; and self-actualisation.

The organisation of knowledge around traditional disciplines and especially the single-subject pattern, like science, has been particularly enduring throughout the twentieth century. This is despite periodic criticisms that such an organisation tends to distort the school curriculum unnecessarily in favour of tertiary studies and lack of consensus 'about the nature of the structure of their discipline' (Goodlad & Su 1992, p. 335). There is a plausible argument that this curriculum organisation may be a reason for the inability of the curriculum to respond to continued criticisms:

Welch (1979) looked back on the pre-college science curriculum development projects funded by the National Science Foundation - all discipline-oriented approaches to curriculum organisation. His conclusion was that in spite of the expenditures of millions of dollars and the involvement of some of the most brilliant scientific minds, the science classroom in the late 1970s was little different from that of 20 years before. Although there may be new books on the shelves and clever gadgets in the storage cabinets, the day-to-day operations of classes are largely unchanged - curriculum and instruction are organised and conducted around the separate school subjects, a pattern of organisation that remains little changed over the years. (Goodlad & Su 1992, p. 336)

Australian secondary school curricula have also tended to be structured around disciplines, especially at the senior (11-12) level, and the more contextualised and interest-based
approaches the 1980s curricula are being replaced by more discipline-based in the 1990s (Fensham 1995).

The present thesis has argued at length that the traditional characterisations of science in the curriculum have been inadequate, and attempts to organise the science curriculum to embody a supposed inherent structure of science - to reflect the discipline - are flawed. Moreover, the mention, above, of the involvement of some of the most brilliant scientific minds suggests a narrowness of curriculum stakeholders that, with respect to the scientists involved, limited each conception of the curriculum. A discipline-based organisation does not have to be in single subjects, but may be as correlated subjects (as in the NSW Science and Technology K-6 syllabus), fused subjects or broad-fields of knowledge (all of which are found in the integrated implementation of the NSW K-6 curriculum in many schools).

A multidimensional school Science has a stronger potential to meet the range of these diverse goals than does a traditional, internalist, school Science. However, the term worthwhile knowledge is vague like all such broad terms, and susceptible to interpretation to suit the interests of any stakeholders. As a result, it does not guarantee a robust characterisation of science; it merely allows for it.

Goals associated with the curriculum as a rational system

Another cluster of general curriculum goals has re-emerged in the 1980s and 1990s in western societies, associated with an increasing influence of conservative economic policy on other public policy, including education policy. In this view, worthwhile knowledge is partly defined by its value to the greater social benefit, including economic and other benefits. Here, the curriculum is interpreted as a rational system for achieving change in educational practice, improving the efficiency of the way the community uses resources for education, and ‘greater consensus on the core values a nation promotes through its education system’ (Elmore and Sykes 1992, p. 195):

Curriculum, in this view, is a rational means for achieving collective social ends and for making improvements on a scale that cannot be achieved by enlightened individual actions. (Elmore & Sykes 1992, p. 195)

This view characterises the curriculum as a rational system that is ‘susceptible to efficient design’ (Elmore & Sykes 1992, p. 198), and its central goal can be characterised as societal
in the sense of meeting societal purposes such as change, efficiency and consensus. It has been popular from time to time, particularly in the US, and has enjoyed a resurgence from the mid-1980s in the managerialist policies that came to characterise public policy in western countries, such as the US, the UK and Australia (Ruby 1991). Criticisms in the 1970s of this approach, that the so-called ‘scientific’ approach of using surveys and external consultants to implement a research and development approach to curriculum, do not seem to figure in the more recent, and still current, political rhetoric of efficiency and the rationally managed curriculum.

The goal of improving the efficient use of resources is linked to goals of increasing national efficiency and economic well-being, especially through ‘improved’ science, mathematics and technology curriculum goals. Ruby (1991) has made this point well. He noted similarities between education systems in the US, the UK, France, New Zealand, Australia and elsewhere, and, perhaps more strikingly, from across the political spectrum: traditional differences in political ideologies concerning the curriculum have diminished. Broadly, these changes call for greater external control over the school curriculum through large-scale testing:

These new reporting and assessment strategies are tied to three shifts in public policy during the 1970s and 1980s. The first is a shift in policy priorities from increasing and monitoring input levels to measuring and improving outcomes. The second is a shift in policy focus from the individual to the cohort or the population. The third is a shift in policy goals from meeting individual needs and aspirations to serving the national interests. Bentham’s notion that serving the needs of individuals would satisfy the needs of the state has been turned on its head: the interests of the nation demand that individuals be educated to the highest level possible. Like the other reforms these new assessment strategies do not totally change structures and systems but aim to make existing practices more effective. They are attempts to improve the quality of outcomes by working harder, making the content tougher, and by ‘making the little buggers work harder’ (Kirst 1988). These intensification efforts are focused on the modal group - they ignore the upper quartile because they are the model for the reforms. They also ignore the bottom quartile because for these children their family and social circumstances and the basic structure of school limit any chance of success. (Ruby 1991, p. 22)

That is, Ruby argues that curriculum goals have shifted in recent years to reflect broader changes in the goals of public policy, namely to improve the scores of widespread testing of learning outcomes, to focus on the educational achievement of the group rather than the individual, and to serve national interests rather than the needs of individual students.
Accepting Ruby's analysis, the present thesis has something to say about each of these goals. First, large-scale testing is restricted traditionally to that which is easily tested and scored by large-scale assessment instruments, namely recall of propositional knowledge, and is unlikely without an explicit effort to reflect a more robust understanding of science as proposed by the present thesis (Fensham 1992, p. 796). Secondly, learning is done by individuals, and therefore the curriculum needs to address such matters as the individual construction of knowledge and the belief systems of individual students (Lawson 1994). Thirdly, a focus on national economic interests, particularly as expressed in formal statements in recent years, dismisses the role of science education in promoting the scientific literacy of its citizens: earlier rhetorics like catering for individual differences feature mainly at the school level and little with the policy elites. This is quite apart from the likely dilution of national interests by pursuing a limited and inadequate characterisation of science. Fourthly, clauses like *making the content tougher* simply beg the question of what is meant by *tougher*. The present chapter will argue later that the scientific rigour of the curriculum arises from a robust representation of a multidimensional characterisation of science, not by increasing the recall of soon-forgotten acontextual knowledge with little sense of the usefulness of science in real contexts. Moreover, a rigorous school Science should be modelled on a robust characterisation of science, and not the achievements of the upper quartile of students in traditional curricula. Such a curriculum model can then be applied to suit the interests, needs and abilities of all students, including those who might be encouraged to pursue further science studies and so also meet national interests.

It is legitimate that pluralist western democracies facing the twenty first century value the contribution of school Science to national well-being, and a multidimensional school Science is well suited to this task. However, the appeal of the curriculum as a rational enterprise rests partly on the unstated benefits of an instrumentalist curriculum to particular stakeholders. This does not acknowledge that such a school Science is also well suited to other curriculum goals, including goals of personal fulfilment and empowerment, and longer term societal competence with scientific and technological matters. To the extent that
these goals are marginalised and even discarded, the characterisation of science in the school curriculum is compromised.

As it stands, a school curriculum predicated on narrowly defined goals of efficiency, accountability, improvement and short term economic benefit implies a characterisation of science that the present thesis rejects as a distortion. Such curriculum goals are consistent with a multidimensional characterisation of science, but at best they do not encourage it and at worst they endorse a flawed characterisation. We will return to this matter briefly, in section 3.4 below, to argue that a multidimensional is better than a traditional characterisation as a basis for school Science meeting these broader social goals.

The curriculum as worthwhile knowledge and as a rational system are policies that explicitly exercise the minds of curriculum stakeholders, and whose goals are those probably expressed most clearly in school Science. The significant question here is the nature of school Science they entail or preclude. If, as has been the trend in western democracies since the 1980s, worthwhile knowledge becomes equated with that which best serves the national interest, and national interest is defined narrowly, then other science curriculum goals are diminished or excluded (Fensham 1995). Decisions such as these are the prerogative of school systems, as is their right in pluralist democracies. What the present thesis challenges is the tendency toward large scale curriculum changes, such as the national curriculum efforts in Australia and the UK, without making informed decisions about their effects on the nature of subjects, such as influencing the character of school Science.

Conclusion: the goals of science education do not reflect the nature of science

The present thesis argues that, based on its analysis, the three traditional goals of science education and general curriculum goals do not reflect the nature of science as characterised in the metascientific literature. While they are consistent with, and give scope for, the multidimensional characterisation of science argued in the present paper, at best they are inadequate in scope and definition, and at worst they give a distorted and incomplete characterisation of science that lacks cohesion and rigour. They are neither as explicit nor as thoroughgoing as the present thesis has argued. Even allowing that Bybee
and DeBoer reviewed research on science curriculum goals, and did not claim to be representing the detail of particular goals, it appears that goals expressed as purposes of the science curriculum are more comprehensive than goals expressed as content to be learned. The traditional expressions of goals as statements of curriculum content (what is to be learned) do not make explicit the scope argued by the present thesis. The tendency of goal statements to be broad allows for extended scope, but in practice this strategy has not lead to broader interpretations. This is the main criticism of existing curriculum goals as they apply to school Science.

2.2 The practice of school Science does not reflect the nature of science

The curriculum literature is replete with examples of curriculum initiatives, including the science curriculum, that have failed to be implemented at every level. This includes criticism, from several quarters, that the practice of school Science does not reflect the nature of science: they include appraisals of student knowledge, teacher knowledge, public understanding, curriculum content, textbook contents, and so forth. Criticism of school Science from most metascientific critiques is generally similar. For example, Matthews (1994) has listed a long history of appeals for HPS studies to be included in science education courses, including science teacher preservice training, and several authors in Lowe (ed., 1987) and Jasanoff et al., (eds, 1995) have made similar critiques from STS perspectives.

Criticisms that in some respects school science inherently misrepresents science

First is the claim that school Science does not necessarily reflect the nature of science. For example, Bernetta (1986) has argued that for much of the twentieth century US biology texts made little or no reference at all to evolution, let alone a robust treatment. The

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5 The term comprehensive is used here to mean a multi-dimensional characterisation of science, as argued by the present thesis.

6 Note the earlier caution against doctrinaire distinctions between metascientific fields like HPS and STS.
physicist Richard Feynman, recalled by Bernetta, has argued that school Science textbooks characterise science poorly because

... the book publishers and the state adoption agencies operate a closed system in which they cyclically reinforce each other’s ignorance, reward each other’s superstitions and preserve science education in this funny realm of Never Never that never never was. (Bernetta 1986, p. ScSh3)

To the extent that texts equate with practice, school Science here does not reflect the nature of science.

Criticisms that learning outcomes from school Science are not good science

From any reading of the science education literature, particularly from the 1980s on, one cannot but be impressed with the staggering rise of studies that report children’s misconceptions of science concepts, and the resistance of these misconceptions to change:

There are approximately twenty-five hundred published studies on children’s misconceptions in science; the information on the resistance of science learning to science instruction is overwhelming (Duit 1995). (Matthews 1994, p. 51)

This alone is sufficient to cause concern whether the three goal clusters are widely met, because it indicates that traditional science curricula and teaching modes are not particularly effective in developing the ideas contained in the curriculum: not for individuals, and therefore not improvement in society; explicitly not the development of scientific understanding; and not the development and application of science skills.

This judgment is reinforced by other data comparing children’s understandings, skills and attitudes with those that characterise science:

But there are also many antieducational factors that are within schools’ competence and influence to affect. One disturbing finding in many of the reports is that the more science students do, the less they like it (Yager & Bonstetter 1984; Brunkhorst & Yager 1986). The National Assessment of Educational Progress data shows that traditional science instruction tends to negate natural interest, and cause some of the best students to pursue other disciplines. In a 1991 report of the National Science Board, Science and Engineering Indicators, nearly thirty percent of all seventh-grader express a preference for a career in science or engineering. This percentage steadily drops through high school, and by the end of high school less than twenty-five percent of boys and, dramatically, less than ten percent of girls express such a career interest (National Science Board, 1991). By the end of the 1980s fully seventy percent of US school students took no more science and mathematics than the minimum required to graduate from high school.

Also of concern is the degree to which even successful science education has failed to transform students’ intellectual outlook. One study found that belief in astrology was largely unaffected by completion of a US science degree: students who commenced the degree program believing in astrology finished the program believing in it. Forty percent of the US population, despite all their years at school,
believe that astrology is scientific; astrology columns are more widely read in newspapers than science columns. (Matthews 1994, pp. 33-4)

This critique also addresses all goal sets: personal and social goals, scientific understanding, and the useful application of scientific techniques, such as reasoning from evidence.

The present thesis shares these concerns that for many students a science education negates their natural interest, is not pursued beyond mandatory enrolment and fails to transform their intellectual outlook. A multidimensional characterisation of science legitimises school Science addressing Matthews’ concerns by basing the school curriculum robustly in the literature. In Matthews’ examples, above, our attention is drawn to students’ beliefs about astronomy and astrology (belief system) and the non-laboratory context in which such students and citizens confront them. If Matthews and others are correct, studying the characteristics of science more systematically will help school systems address the educational, personal and social concerns he raises.

A related concern is that both the goals and implementation of school Science misrepresent science by relying unduly on unrelated, acontextual facts and concepts, without regard to any meaningful understanding. This has its roots in the nineteenth century (DeBoer 1991) but persists a century later. The focus on concepts, noted above, has in the first place been at the expense of ‘much of the descriptive knowledge and the historical and applied aspects of science’ (Fensham 1992, p. 794). In the second place, it has been adopted in a manner contrary to its original rationale:

The intentions for the understanding of the role of concepts in science have not, however, been successfully included. Many current curricula are now overpacked with the sterile or rote learning of concepts in the absence of an appreciation of how these concepts originated in the data of science in the real world. (Fensham 1992, p. 794)

It would seem, then, that the rationale for a treatment in depth, including developing an understanding of context, value and application, has not translated in classrooms; the rationale for covering more concepts, however, has.
Associated concerns about public science literacy

Related to these concerns over natural interest and intellectual outlook are concerns that these deficient outcomes adversely affect public scientific literacy. Many studies of the public understanding of science have shown very low understandings by the public (Matthews 1994; Wynne 1994). Many constructivist studies of students' understandings of science concepts show considerable mismatches with accepted scientific understandings even among tertiary science and technology students, who would have numbered among the most able and most interested science students when at school (Wandersee, Mintzes & Novak 1994). These examples indicate a considerable body of evidence for rejecting a claim that the learning outcomes of school Science reflect the nature of science. We have discussed the public understanding of science in chapter 11 and Appendix B.6, and will apply the present thesis to it in section 3.5 below, but the point here is the links that are claimed between criticisms of public science literacy and school Science education:

Science education remains what it has been for decades: an indoctrination in an objectivist conception of science and epistemology and a breeding ground for uncritical and scientifically illiterate citizens. (Roth, McGinn & Bowen 1996, p. 455)

This critique links a particular set of beliefs about the world and knowledge of it (objectivist conception of science and technology) and a restricted sense of science knowledge (indoctrination rather than critical understanding) to lack of scientific literacy. This combination of factors is significant and we will pursue the public understanding of science in section 3.5 below.

2.3 The practice of school Science does not reflect the goals of science education

Just as there are criticisms that the practice of school Science does not reflect the nature of science, so too there are concerns expressed from various sources that the enacted curriculum does not match its goals. For example, where the curriculum is organised around student interest and development, the central goal is to foster these qualities in students. This has attracted considerable theoretical interest and enjoys support from teachers as an educational principle, especially at primary (K-6) levels, but has had much
less impact on the formal curriculum, especially the secondary curriculum. Goodlad and Su (1992, p. 336) have suggested three reasons for this: the probable non-compliance of schools with the community’s expectations of standards and scope (the second of Eisner’s senses of problematic subjects); the difficulty of constructing worthwhile educational experiences in response to the often ephemeral interests of students; and the difficulty of students expressing an interest in what they have not yet learned. That is, there are often good reasons for this circumstance:

Most teachers conscientiously try to deliver the curriculum already specified. They depart from it at their risk. Given the preceding traps and teachers’ propensities, we should not be surprised to learn that curricula organised around students’ interests are nonevents. This conclusion does not negate another conclusion: Many teachers do attempt to motivate learning by endeavouring to connect what they want to teach to students’ expressed interests. However, such efforts are pedagogical devices designed to attract students to a prearranged (and usually subject-oriented) curriculum. They fall short of providing alternative patterns of organisation. (Goodlad & Su 1992, pp. 336-7)

Fensham has also noted this effect, reporting that evaluations of the 1950/1960s curricula in the 1970s and 1980s revealed that the intentions of the curriculum developers were not well reflected generally in classrooms. He cautions against being overly critical of the teachers’ role:

[I]t is wrong to conclude that this indicates necessarily a deficit on the part of teachers. The teacher’s first responsibility is to a particular classroom. Teachers have to interpret the images the curriculum conjures up to them in order to translate these images into a curriculum-in-classroom-use. Ben-Peretz (1975) used the term “curriculum potential” to describe the creative but unintended (by the developers) uses by teachers of some project materials. (Fensham 1992, p. 794)

That is, it is an issue for curriculum developers to address rather than a deficit on the part of teachers.

In many examples the goals of school science concern the nature of science, and these are better summarised by saying that the enacted curriculum matches neither the goals nor the nature of science. Taking learning outcomes as a measure of the enacted curriculum, Hanbury Brown (1986, p. 156), for example, has reported that a poll of US citizens showed 44% held beliefs consistent with special creationism (a short cosmological history, divine creation of humans and little change of life forms) and inconsistent with evolution. This is a special debate that is addressed in more detail in section 3.2 below, but here the
observed outcomes match neither the curriculum goal nor the nature of science because the goal of acquiring science knowledge includes accepted science knowledge.

Examples of mismatches between the enacted and idealised science curriculum arise from the broad perspective of all curriculum goals: they reflect the complexities of the learning and teaching processes, the running of schools, the plethora of goals and pressures that affect schools, and so on. The curriculum literature is replete with studies of these issues, but an example from science curriculum is conveyed nicely by Eijkelhof and Kortland in their analysis of the Dutch Physics Curriculum Development Project (PLON):

> It would be very premature to draw, in 1988, final conclusions about the impact of the PLON project on science education, particularly on the teaching of physics. Processes of change in education take a long time and are influenced by many factors from inside and outside education, such as teachers’ salaries, class size, structure of education, job education, job opportunities, teacher training, new examination programs, etc. Innovators’ feelings often drift between hope and fear. (Eijkelhof & Kortland 1988, p. 303)

This is especially relevant given two factors we have discussed already as associated with the science curriculum. One is Eisner’s notion of curriculum subjects such as Science being problematic when they receive high expectations and the consequent likelihood of these expectations not being met. The second contributes to the first, namely the competing interests of many stakeholders, a recurring theme in the present thesis.

2.4 *School Science does not reflect the nature of science*

In summary, there are strong grounds for rejecting claims that traditional science education goals are well grounded in current, scholarly understandings of the nature of science. The conclusion from the present analysis of the metascientific and science education literatures is that the three traditional, broad science curriculum goals are not met. Therefore, the inclusion of science in the school curriculum is not justified based on these goals. That is, school Science does not adequately represent science as characterised in the metascientific literature. This does not in itself mean that school or traditional science education goals are not justified. Rather, it means that they are not justified as robustly characterising the scientific and metascientific literatures: they cannot claim the authority of being well grounded in those literatures.
Taken together, sections 2.1, 2.2 and 2.3, above, comprise a strong argument that the practice of school Science does not reflect the nature of science as characterised in the metascientific literature. This is despite the express intention of many science curriculum goals and science educators to convey the character of science. However, as argued above, most science education goals and practice are based on characterisations of science that are limited, non-rigorous, frequently disputed outright in the metascientific literature, and at odds with current scientific literatures. In addition, the implementation of school Science, like the implementation of most school subjects, falls short of its stated goals. Therefore, it cannot claim to represent science, at least in any robust or rigorous sense.

2.5 The failure of school Science to reflect the nature of science compromises the justification for science being in the school curriculum

If the justification for science being included in the school curriculum is that the nature of science contributes to the general goal cluster of the curriculum, and if neither the goals nor the practice of school Science reflects the nature of science, then the very rationale for science being included in the school curriculum is compromised. Whether science is included because of its contribution to the mental discipline of students, enculturation in a significant human enterprise, significant other personal and social outcomes, national benefits, or personal understanding of the material world, or some combination of these, these goals arise largely through the perceived nature of science. Now it could be argued that the traditional, restricted characterisation of science for school Science is sufficient, or even better suited, for these curriculum goals. The present thesis rejects this argument because it found that science is characterised in multiple, interacting dimensions. At best a traditional, internalist characterisation of science does not make this clear; at worst it distorts science by neglecting significant aspects of the character of science and variations in interpretation. An education in science, rather than an indoctrination in it, must equip students for the complexities of science, its uses and mis-uses, and the capacity to deal with novel arguments. These are reasons for science being in the school curriculum. They can
arise from a robust, multidimensional characterisation of science, of the sort argued here. They do not arise from the sort of school Science that is subject to the criticisms given above.
3 The present thesis applies to science curriculum issues.

The present thesis applies to issues involving the nature of science as it is characterised in the science curriculum. In showing how science can be better characterised, it suggests how these issues can be addressed. We will examine six examples of current debates that have implications for the science curriculum, and therefore about which the present thesis should be expected to contribute. The examples were chosen simply because, in the author’s experience of curriculum development, they recur as significant to curriculum stakeholders. These debates are about:

3.1 rigour in the science curriculum;
3.2 the inclusion of so-called creation science in the curriculum;
3.3 conservative versus progressive (right-wing versus left-wing) views about the curriculum;
3.4 the contribution of science education to the national economy;
3.5 the public understanding of science; and
3.6 the relationship between science and technology.

Some of these are interrelated, but are addressed separately here because each has been a substantial focus of public discussion.

3.1 Rigour in the science curriculum

The notion of rigour is often invoked in discussions about the curriculum, as for example by the NSW Minister for Education and Training (Aquilina 1997). In science education it is invoked usually in arguing for a thorough treatment of scientific concepts and mathematical manipulations; by contrast, studies of science in its social context are dismissed as less rigorous. Where this concept of rigour is specified, it is based on the empirical foundations of scientific knowledge and the logic and rationality of scientific deductions and mathematical analysis. Often rigour is vaguely specified or used without elaboration or justification, which appears to be antithetical to the very notion of rigour itself.
Rigour is taken here to mean exactitude and rigidly accurate adherence to rules:

Rigour:
2. the full or extreme severity of laws, rules, etc.: the rigour of the law (The Macquarie Dictionary; emphasis in original).

The obvious questions are, Which rules, or Whose rules? The present thesis argues that the rigour of a public document like a curriculum syllabus cannot be demonstrated unless at least it conforms to its literature, which is available to and arises from informed scholarly and public debate and scrutiny. That is, the literature comprises argument that can be constructed and scrutinised with care by all interested parties. This is not to argue that school Science is the same as science per se. Rather, it is to argue that to the extent school Science purports to represent actual science, or sciences, it must show that it conforms to the scientific and metascientific literatures. To the extent that school Science embodies other considerations, such as theories of learning and pedagogy, it must also show that it conforms to those literatures to demonstrate its rigour. Thus the following paragraphs comprise an argument for curriculum rigour concerning the subject Science.

(i) There exists a body of extended, defended, critiqued, and publicly available argument about the nature of science, comprising contributions from individuals and groups widely recognised in society as capable of identifying and critiquing the rigour of science claims, including practising scientists, philosophers of science, historians of science, sociologists of science and contributors to science policy. This body of argument comprises the metascientific literature.

(ii) The present thesis argues that any claim to rigour must at least demonstrate adherence to this body of critiqued and authoritative argument in the metascientific literature. It further argues that this literature characterises science in a complex, multidimensional fashion, and suggests that this complex characterisation can be better understood in terms of knowledge, activity, purpose, structure, context and belief system, than it can by traditional categories of characterisation. For example, simplistic, uncontested, positivistic characterisations of science make it difficult to reconcile the widely accepted claims that science knowledge is both authoritative and tentative. However, examination of science belief systems, purposes, contexts
and activities shows clearly that science knowledge can be both authoritative and tentative, in specialised senses of these terms, due at least to its empirical basis, naturalistic beliefs, retesting of claims, the criteria for judgements, and competing interpretations of meaning.

(iii) The present thesis also applies to a curriculum framework that has traditionally included a subject called Science, and that subject has traditionally claimed a relationship to something larger in society, also called science. That is, they are explicit decisions that the characteristics of science should be in the curriculum, and that the school subject bears some relation to science, or the sciences, per se. On the basis of these decisions, the present thesis then seeks to inform any decision about the correspondence between school Science and science.

(iv) Debate about the nature of science in the school curriculum arises partly because the assumptions about rigour and the criteria for establishing it are typically inexplicit and poorly grounded. Rigour in school Science arises from several sources, including: the explicit treatment of scientific belief systems, particularly the assumptions and criteria for making judgements; the explicit treatment of scientific structures, particularly the structures of logical arguments and scientific language; the explicit treatment of the multiple, interactive, dimensions of science, such as the interplay of beliefs, purposes and activities; and the use of teaching and assessment strategies that promote students’ intellectual engagement with these characteristics.

(v) Adoption of a particular view of science based on poorly grounded debate is no guarantee of rigour, and at best can marshal only slim support for any claim to rigour. In Australia, final curriculum documents typically present only a particular characterisation without any demonstration of rigour, whether or not competing views of science have been proffered in the preceding curriculum debates. In such a circumstance, rigour is tacitly equated with the dominant or agreed view of the curriculum stakeholders concerned. However, the agreement about the dominant view typically arises from a process of negotiation between stakeholders
(McKinnon 1991; Winder 1991; Walker 1991); the substance of argument in these negotiations is not made explicit. Attempts to ground the rationale in the literature are limited and sometimes specious: curriculum documents, such as syllabuses, policy documents and text books, show little evidence of broad and robust grounding. For example, the Science Profile that was part of the Australian national curriculum framework project (Curriculum Corporation 1994) implies a characterisation of science, but this is inadequate in several respects: it does not show that there is a variety of views about science, nor does it illuminate any main views; it does not show the multidimensional character of science, as the present thesis advocates; it bears little relationship to the content strands, that reinforce traditional, positivist (uncontested) views of discipline-based propositional knowledge; and it gives little idea of how the statement on the nature of science can be translated into the detail of the later sections. These criticisms apply even more strongly to the NSW science syllabuses, especially at the secondary school level, most of which have little to say about the nature of science, and even less to say about presenting more than a positivist, discipline-based knowledge of science concepts and investigative processes. Thus an argument for rigour that is based on a particular specialist representation in the curriculum development process can fail also because that process has no explicit means of identifying and securing that rigour. The present thesis argues that such a process can claim no more than unsupported agreement on a particular view and does not demonstrate rigour.

Such a process, of determining curriculum content by publicly unsupported argument, is open to influence and even control by interest groups of whatever ideological persuasion, whether academic, political, religious, social or economic. Ideology is in itself not a bad thing; as noted earlier in this chapter, any statement of curriculum goals represents a mix of educational and other ideologies. Also, as previously mentioned, the present thesis is committed to a liberal, pluralistic

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7 Criticisms of the statement of the nature of science in draft materials for the profile were widely criticised in the media, for example from the Australian Academy of Science (1993).
democracy (itself an ideology), and part of that setting is acceptance that groups within such a society will compete for ideas and policy control. However, the present thesis has argued that a characterisation of school Science that is grounded explicitly in the metascientific literature makes this grounding clear by definition. That is, the basis for making curriculum decisions about the nature of science should be open and transparent.

A counter argument to the points (i) to (vi) above is simply to argue that the school Science education of potential scientists and technologists has no time to be concerned with anything but an essentially internalist curriculum. This view is often argued by claiming that the increasing amount of scientific knowledge creates pressure for more science knowledge to be covered, not less. There are several responses to this argument besides those given above.

Rigour and the school education of scientists

First are arguments associated with the goal of providing a sound basis for the future education of scientists and technologists. The general response is that a traditional, internalist science curriculum is inadequate for the preparation of potential scientists and technologists.

(i) The essentially internalist and positivist character of school Science is strongly contested in the metascientific literature and science education literature concerned with the nature of science. Metascientific argument covered in the present paper has shown that positivist science has satisfied neither its own criteria, such as the principle of verification, nor criticisms from non-positivist accounts. There are compelling arguments that a strictly internalist account of science fails to appreciate the role of the scientific community and its interactions with the wider community, and is wrong in implying the scientific ideas develop according to their internal logic alone. That is, the traditional approach is not only less adequate, but less rigorous.

(ii) The strongest case for a strongly internalist and positivist school Science seems only to be appeal to tradition. In overall structure, Australian school Science
curricula were established during the influence of the positivist Received View of science, but have not fundamentally changed since that view was discredited.

(iii) There are plausible, even compelling, arguments that a broader notion of context than simply the cognitive actually characterises science, and that to fail to account for this is to fail to understand how science actually works. It is to fail to provide a scientific rationale, reducing scientific commitment to poorly justified belief. That is, a multidimensional characterisation is more rigorous.

(iv) Although of derivative concern to the present thesis, the science education literature also argues that robust understanding of scientific concepts will develop by more time being spent on fewer concepts, rather than addressing more concepts or, worse, masses of poorly related facts (DeBoer 1991, p. 222). While this in itself does not preclude a strongly internalist approach, when combined with studies showing increased understanding resulting from a broader appreciation of context, the traditional internalism of school Science is also poorly grounded in learning theory.

(v) For these reasons, the education of future scientists and technologists is likely to be enhanced rather than diminished by a multidimensional characterisation. Students would, for example, develop: a more thorough understanding of (fewer) concepts; an appreciation of the rate of change and the scope of science knowledge; and an ability to appraise the soundness of science claims both within the science community and more broadly in society, through an appreciation of science knowledge, beliefs, criteria, structure, purpose, activity, and context.

(vi) Many of the most significant issues confronting societies today are based in science and technology, and most of these can be neither understood nor resolved using internalist science arguments alone. There is a growing literature dealing with the public perception of science and the way the public interact with science-related issues. In matters as diverse as superstitions, ecology and nutrition, to name but a few, the opinion of the scientist is one among many and sometimes one among a number of scientific opinions. An internalist argument - one comprising
propositions of scientific concepts - will not win the day necessarily, because such issues involve more than scientific propositions. From a public perspective the situation is even more nonsensical when expert opinions differ, because each expert constructs a different internalist argument.

(v) This creates the prospect of scientists, able to act only as mere technicians, having less appreciation than interested non-scientists of how the broader picture of science works in practice. This has strong implications for the control of science: while certainly not arguing for the complete autonomy of the scientific community, it creates the possibility of policy makers, corporations and public and private interest groups controlling science without regarding the views of the practitioners. In the companion chapter on context and Appendix B.1, we noted that the substantial portion of scientific research is funded either by private interests such as business or particular interests arising from government and semi-government policy, including military and other targeted funds. We also noted increasingly strong community interest in other scientific activity, such as by animal welfare, environmental and reproductive technology interest groups. Thus the dependency of scientific research on specific funding becomes increasingly evident, as is the ability for external groups to instigate, redirect, halt or in other ways alter scientific research. These are legitimate processes in a pluralistic democracy. However, scientists unable to appreciate and address these factors are severely restricted in the contributions they can make.

(vi) It ignores the pressure, addressed by the present thesis, for a more scientifically literate public. It is often the case, and increasingly so from the last quarter of the twentieth century, that the general public expects and is likely to achieve greater involvement in the running and funding of science. The view, during the nineteenth and into the twentieth centuries, that science was benign and perhaps all-powerful, dissipated in the second half of the twentieth century with public concern over the role of science in non-benign issues, such as military developments and pollution, and the failure of science to deliver expected benefits,
such as curing serious illnesses. This shift in public perception is well documented. Aligned with this shift has been a shift towards increasing public and government intervention. The popular image of the disinterested and talented scientist pursuing an individual enthusiasm applies to an increasingly insignificant minority. From these trends and the present characteristics of science, it is most probable that the science of the future will be even more of a public and corporate enterprise, and the scientist of the future will need expertise in achieving in that culture. An internalist curriculum is unlikely to prepare scientists with those abilities.

Rigour and the goal of public understanding

Second are arguments associated with the goal of preparing a scientifically literate citizenry. In seeking to serve the future needs of an educated citizenry, the above arguments, of intelligibility, real-world understandings and rigour, still apply, but more strongly. The intelligibility argument is more significant because the range of school students would also include students of all abilities, including those of whatever ability who find acontextual, internalist, science unappealing. Even if the internalist argument, that political, personal, economic and other factors should not apply to ‘good’ science, is advocated for particular approaches or subjects, the evidence is undeniable that they do apply in ‘real-world’ science, meaning science as it is practised both within the scientific community and in science-society issues. In both contexts a multidimensional characterisation of science makes the nature of science clearer; in particular, informed public debate about scientific issues requires this real-world, multidimensional understanding. We will address the public understanding of science as a curriculum issue in section (e) below, but it is clear that the notion of an educated, ‘scientifically literate citizen’ would refer to some understanding of science ‘in the real world’, and not just its frameworks of concepts and propositions of knowledge-that.
Rigour and the multiple goals of the general curriculum

Third are arguments associated with broader clusters of curriculum goals, where the science curriculum is viewed as a means of serving the future needs of an educated citizenry and, as a subset of this group or as a separate set, future scientists and technicians. In this case, all the above arguments still apply. To argue some sort of externalist characterisation for a generalist stream but an internalist characterisation for an ‘elite’ stream, is simply to confuse the curriculum development by introducing prematurely how the curriculum should be constructed, a question of means, without having determined what should be in it, a question of ends. At the very least this can distort the nature of school Science, making the science curriculum less rigorous. The present thesis is clear about the need for science in the general school curriculum to be characterised more rigorously and comprehensively, along with being more engaging, enriching and empowering for students. A multidimensional characterisation of science has this capacity. The question for curriculum developers should be how to construct a curriculum that provides a multidimensional characterisation of science for all students.
3.2 The debate about evolution and special creationism in the science curriculum

There is long-running debate over whether special creationism - often called by its proponents creation science - should be included in the school Science curriculum either alongside or instead of evolutionary theory. This debate is a nice example of debate by curriculum stakeholders about the nature of school Science, and a specific example of debate about curriculum content. Venezky (1992, p. 447) has described the US debate over theories of evolution and special creationism in biology textbooks as a 'battleground in the social control power struggle' to influence the curriculum by influencing the content of school textbooks. He argues that for much of the twentieth century in the US, many biology textbooks made little or no mention of evolutionary theory, despite its centrality to biology and complementarity with theories in other science fields. Further, a number of US states passed legislation either barring the teaching of evolution or requiring equal time for special creationism:

In 1920 Oklahoma outlawed the use of textbooks that taught evolution, and a few years later Tennessee barred the teaching of evolution, whether from a textbook or any other source.

The Scopes trial, held in Dayton, Tennessee, in 1925, involved a high school teacher, John Thomas Scopes, who agreed to test the validity of the state law banning evolution from schools ... [T]he case presented the first of a series of skirmishes between science and society. The prosecution won the case, only to be reversed at the state level on a technicality. But the statute against the teaching of evolution remained on the books in Tennessee.

Soon after the Scopes case was resolved, Mississippi and Arkansas passed similar laws barring the teaching of evolution. It was the Arkansas law, known as the Rotenberry Act, that reached the Supreme Court in 1968. The court then ruled that it was illegal to bar the teaching of evolution in public schools and colleges (De Camp 1969). Tennessee countered in 1973 with a law requiring equal time for special creation - that is, the Genesis version of how life began. The California Board of Education had adopted a similar position in 1969. 'The] Book of Genesis presents a reasonable explanation of the origin of life ... special creation should be taught as an alternative to the theory of organic evolution' (cited in Nelkin 1976). The Tennessee equal time law was declared unconstitutional by the Supreme Court and was repealed in 1975. The California Board of Education, in the meantime, also reversed itself and pressed publishers for a more extensive treatment of evolution in biology texts.

In viewing the evolution controversies, it is critical to understand the nature of the present-day objectors. They are not mainly the residents of rural Appalachia, but middle-class citizens from areas like southern California and urban Texas, many with technical training (Nelkin 1976). Fundamentalist movements grew rapidly in these areas in the late 1960s, perhaps as a response to the uncertainties of technology. Creation research centers [sic] were established, and creationism was pushed as a valid, scientific concept. In parallel, high school courses and texts
that taught evolution or that appeared to give science a role greater than that of religion were attacked. Programs like MACOS suffered from these movements, as did a number of specific textbooks (Conlon & Dow 1975). (Venezky 1992, pp. 447-8)

This passage from Venezky raises several matters of interest to the present thesis. Some issues are more general than the particular issue of special creationism and evolution, and some are specific to it.

*Effects of legislation on the curriculum*

First is the general matter of legislatively determining the content of the school curriculum: this is a much broader curriculum issue than the particular matter of special creationism. It concerns any example where curriculum stakeholders seek to define in legislation what is science for the purposes of the school curriculum. Like the matter of special creationism, it may also arise from the ideological goals of particular religious orthodoxies. For example, the present author was once asked to provide confidential advice to a school system about a non-mainstream view of science. The school system had a request from a particular religious group for their children to be exempted from any association with microchip technology. The reason for the request was that this group had identified microchip technology with the Antichrist. The immediate implications of such a request were that students would have had to have been exempted from using computers, videos, and so forth, in class. The broader implications for science education were that they also would have been excluded from learning *about* microchip technologies. The effect for these children was to present a view of science that is not endorsed, either by the scientific community or mainstream education systems.

The impact of legislative approaches may also arise from curriculum goals arising from other than religious orthodoxies. For example, we have noted above that curriculum goals are influenced increasingly by broader government policy. Thus, where the curriculum is viewed as a rational system, it is under pressure for its (state-defined) efficiency and accountability to be quantified and improved, partly by the mass testing of student learning outcomes. The implication for the enacted science curriculum is that curriculum content becomes that which is tested easily by large-scale instruments.
Traditionally such instruments have favoured common content and low-order intellectual skills such as recall of propositional knowledge and formula manipulation. This opposes the multidimensional characterisation of science advocated by the present thesis, which calls for a demonstration of understanding of both knowledge-that and knowledge-how, of analysis of contextualised science issues, purposes, and so forth. The same argument applies where the goals of science education are to serve the economic and other needs of society in training our future scientists and technologists; this is pursued in section 3.4 below. Alternatively, policies that view the curriculum as capital emphasise the value of credentials conferred by a science education, where the pressure on the science curriculum is to cover that content covered by the exit credential. Where that credential is awarded on the basis of external examinations, as in the NSW context, the pressure is to teach to the test.

The general point implied by Venezky, and supported by the present thesis, is that legislative determination of the curriculum is, ultimately, a reflection of the legislative process, and is no guarantee that a school subject, in this case Science, reflects the literature of the field with the same title, *science*. Whether or not the curriculum is set out in legislation, there must be some mechanism within the curriculum development process that accounts for the literature that analyses the field. Where the society claims to be a pluralistic, participatory democracy, then that process must be open to participation, scrutiny and revision. There is, of course, the possibility that legislation could be enacted to require curriculum development to take account of the literature. However, examples where the curriculum has been legislated to a greater or lesser extent, such as the Education Reform Act of 1990 in NSW and the national curriculum in the UK (Pring 1989), have shown that legislators have not taken that option, instead legislating for frameworks (NSW) or frameworks and content (UK). In NSW the government delegates the role of curriculum development to the statutory Board of Studies, but there is no requirement by regulation or even public advice to demonstrate particular standards of scholarly analysis.
Effects of textbooks on the curriculum

The second matter raised in Venezky’s discussion is the role of textbooks in determining curriculum content. This is probably more of an issue in US education systems, where school texts are endorsed at a system or board level, rather than in Australia, where decisions about school texts are made mostly at the individual school level. Nonetheless, the general proposition remains that school texts present a view of the nature of science, whether explicitly or not. There is widespread criticism from metascientists that school Science texts address the nature of science poorly, such as by: providing a distorted reconstruction of science (Singer 1959); omitting the very historical detail that illuminates a particular scientific argument (Matthews 1994); tending to demand low-level cognitive processes, focus on presenting knowledge content, impose time structures on the coverage of the program, and encourage ‘cookbook’ type experimental activities (Tobin, Tippins & Gallard 1994); using rhetorical devices that are not made explicit (Lewenstein 1995); and with using technocratic and uncritical characterisations of science (Edge 1995). The present thesis argues that a multidimensional characterisation of science addresses each of these criticisms.

Effects of a science education on curriculum decisions

The third matter raised by Venezky is the role of curriculum stakeholders, many with technical training, who objected to the teaching of a theory that the relevant scientific community judges as central to the field. By implication, Venezky finds it especially remarkable that technical training, presumably built on a solid foundation of school Science education, provides no guarantee that curriculum stakeholders would not reject a central tenet of science. Similarly Hanbury Brown (1986, p. 157) has noted that many creationists ‘come from the technically trained middle class’, but explains this as part of a traditional conflict between faith and rationalism, where religious fundamentalism seeks to use reason to support and even demonstrate religious faith.

In response, the present thesis does not advocate that science education should be an indoctrination into science, especially to the exclusion of other elements of a broad school
education. Rather, the response is that a science education should make clear the belief system(s) that underpin science, and enable citizens to identify and analyse conflicts (and agreements) between belief systems used by scientists and others in society. Merely learning propositions of science knowledge, devoid of purpose or meaningful context, and with basic assumptions unexamined, as with traditional science curricula, is clearly inadequate preparation for evaluating competing belief systems.

**Effects of attitudes to science and technology on curriculum decisions**

Fourth is Venezky's suggestion that even the well-educated middle classes, including those with technical training, have adopted an anti-science stand *perhaps as a response to the uncertainties of technology*. Again there is the inference that science education has left citizens unprepared to analyse scientific issues, in this case the rapid pace of development and its impacts on their lives. Again, the response must be for the school Science curriculum to provide for an appreciation of the multidimensional character of science, such as the rapid growth of scientific knowledge, and the purposes and contexts of its creation and uses.

**Effects of separation of church and state, and rhetorics of citizens' rights**

Fifth is the contribution to this particular debate of two issues that probably characterise US society more than most other western societies: the separation of church and state, and the rhetoric of citizens' rights. These are tacit in Venezky's passage no doubt because they are presumed knowledge by his (mainly US) audience. The separation of church and state in the US meant that this part of the science curriculum content was argued on the basis of whether the court ruled that special creationism was a scientific theory, and therefore part of the science curriculum, or a religious tenet, and therefore constitutionally forbidden from US schools. The significance of the legal location of this debate is noted by Strahan (1987) in his description of the successful challenge to the 1981 Arkansas *Balanced Treatment of Creation-Science and Evolution-Science Act* by a coalition of civil libertarian, Protestant, Catholic and Jewish groups:
Many biologists and geologists were called as expert witnesses. The defendant included the Arkansas Department of Education and several of its committees and officers. Their witnesses were mainly Creation 'Scientists'.

The trial was held in December 1981 and resulted in a clear verdict on all counts for the plaintiffs. In his decision, the judge ruled that Creation ‘Science’ is no more nor less than a particular religious doctrine and that a law enforcing its teaching in government schools is therefore unconstitutional. The Act has therefore been removed from the Arkansas statute books.

Scientists around the world can take some comfort from this case - for it could conceivably have gone the other way - but it can be no more than cold comfort. While it would have been very convenient for fundamentalists to have the teaching of Creation ‘Science’ blessed by law, absence of legislative enforcement will not reduce their continued pressure on individual school boards and parent organisations in the USA and elsewhere. (Strahan 1987, p. 10)

That is, the debate about the nature of science in the curriculum took place in the challenge to the 1981 Act - in a legal framework - because presumably it was not provided for in the curriculum development process. Strahan is correct in noting that a legal victory can be only cold comfort: the 1997 Australian legal challenge by the geologist Ian Plimer against the Creationist Allen Roberts is such an example. Plimer’s challenge was on the basis that Roberts’ claims contravened fair trading legislation; the court ruled that, although Roberts’ claims were scientifically misleading in some respects, he was not engaged in trading under the meaning of the Act, and so was not guilty of contravening that Act (Williams 1997a, 1997b, 1997c, 1998; Hemsley 1997). Moreover, Strahan later noted that in the state of Queensland, Australia, equal time for creationism and evolution in the science curriculum was won without legislation or even parliamentary debate. In that case the debate was not part of the curriculum development process, either, and Strahan stresses the intention of avoiding debate as a means of influencing the science curriculum:

In a debate, two points of view are assumed to be of equal importance ... Hence the rejection of the method of debate as a teaching tool in our ministry. (Ham 1980, as quoted by Strahan 1987, p. 11)

In the companion chapter on context and Appendix B.1 we discussed boundary work as the means by which different groups seek to demarcate what is science from what is non-science. Strahan’s use here of inverted commas in Creation ‘Science’ to distinguish it from science is noteworthy as an example of boundary work. Equally, Ham engages in boundary work from the other side:

The Creation Science Ministry teaches both the Biblical and scientific facts of creation. The aim is to show how this teaching is related to the Gospel and basic to the truth of the Fall of man [sic] ...
Especially it is pleasing to find the [creationist] books in the right section of the [school] libraries under Science and History instead of Religion as the atheistic Dewey system would require. (Ham 1980, as quoted by Strahan 1987, pp. 10-11)

This is not to argue for a complete relativism here. To the extent that this passage from Ham represents special creationism, the present thesis has shown that the aim of showing how scientific claims relate to religious texts (the Gospel) has long gone from science and conflicts with the widely held purpose of science to provide naturalistic explanations with empirical support. Further, the Fall of man is an axiological concept, specifically a religious one, and generally agreed to be beyond the limits of what empirically based knowledge can tell us, that is, non-science.

*The scientific credentials of special creationism*

Sixth from Venezky’s passage is the specific issue of whether special creationism does belong in the science curriculum. The basis for this decision is whether special creationism is a valid scientific theory: whether or not it may be an alternative to evolution. A number of factors cloud debate on this issue, which is another reason why this example is useful in highlighting potential difficulties in determining the nature of science in the school curriculum. Complicating factors include the US constitutional separation of church and state, as we have mentioned, the (mainly) US rhetoric of citizens’ rights, and the emotive issue of religious belief. We will use these three issues as foci for analysis of the case for special creationism in school Science.

This argument, of which Venezky’s is an example, can be interpreted using a multidimensional characterisation of science, as follows. A subject, such as Science, is included in the curriculum on the basis that it reflects a broadly accepted, well informed view in society of the nature of science. The present thesis has shown that such a view is complex. That complexity should be reflected in a science curriculum for all citizens. Debate about whether particular views, such as special creationism, are science, and therefore included in the curriculum as science, should be part of the curriculum development process. The curriculum development process is better able to compare views, and make informed judgments about them, when it makes the characteristics of science explicit, for example using a multidimensional characterisation as advocated by the present
thesis. That is, whether these sorts of debates are argued in the courts, or (preferably) in the curriculum development process, they need an analysis such as the present thesis to do this job well.

3.2.1 The impact of separation of church and state on this issue of the science curriculum

There can be not only legal but political arguments brought to bear on science in the curriculum, as with the US constitutional separation of church and state, whose effect has been to exclude religion from the school curriculum (Strahan 1987; Sockett 1992). The response of the special creationist movement has been, variously, to argue that special creationism is scientific, and therefore has a place in the science curriculum, or alternatively that evolution is simply a religious belief, and therefore it should be excluded from the science curriculum (Strahan 1987, p. 9). Clearly, one cannot have it both ways and argue that evolution is scientific (but so is special creationism) or that it is not scientific (and is a religious belief instead). In the examples of evolution and special creationism, as in all others, the place of each theory in the curriculum must be argued on its own merits. Again, a multidimensional characterisation can clarify the issues.

The present thesis interprets the claim that evolution is a religious belief as highlighting the role of beliefs in characterising science to the neglect of the larger belief system and other dimensions of science such as purpose, activity and knowledge. In this respect it would be possible to think of all human endeavours as belief systems of one sort or another: science, religion, mathematics, history, art and so forth. This is a distortion: the present thesis argues that beliefs alone do not characterise science, but do so in combination with characteristic activities, purposes, structures and so forth8. Mainstream curriculum developers accept that evolutionary theory is scientific and deserving a place in the science curriculum because the relevant scientific community accepts it as a scientific theory: it gives a naturalistic explanation of observed phenomena; it is testable (sustains predictions); it is in principle revisable (falsifiable), and as such makes no claims to absolute truth but

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8 At the end of this chapter we will speculate about other fields also sharing these dimensions.
rather to the best empirical knowledge we have at the time; it is consistent with other successful theories and understandings used by scientists (Strahan 1987; Archer 1987).

The many claims by creationists that evolution is refuted by science draw on a range of scientific expertise that is difficult for the lay person, or even the science trained without relevant expertise, including scientists from other fields and science teachers, to judge. Nonetheless, detailed examination of these claims by scientists with the relevant expertise shows that each of these objections is rejected by the relevant scientific communities (Archer 1986). For the present thesis, evolutionary theory conforms with widely endorsed understandings of scientific belief systems (in its naturalistic beliefs, assumptions and criteria for decisions), knowledge (in being consistent with scientific knowledge from other theories), purpose (in seeking a naturalistic explanation that meets agreed criteria), context (in its acceptance by scientists with relevant, accredited expertise, that is, in both its intellectual and disciplinary contexts) and activity (by arising from characteristic scientific activity and sustaining predictions). So for the purpose of the school curriculum, we find that the belief system embodied in evolutionary theory meets the criteria of scientific belief systems, and in combination with other dimensions of science; therefore it may be included in the science curriculum. Whether it is also a religious belief system is beyond the scope of the present thesis, but it lacks belief in a supernatural power that typically characterises religious belief systems.

Turning to special creationism, we find claims that it is a religion (Ham 1980, quoted by Strahan 1987) and that it is scientific (Bliss 1978). We will concern ourselves only with the claim that special creationism is scientific; if it is a religion, then it belongs elsewhere in the curriculum, not as science. The claim that it is scientific can be judged using the multidimensional analysis developed for characterising science in the present thesis. Here we find that a number of characteristics of special creationism differ significantly in several respects from those used to characterise science, using the dimensions demonstrated by the present thesis to characterise science. These differences are found in: its belief system (God as a causal agent in Nature, belief in the absolute truth of biblical text, and biblical text as a higher criterion of authority than empirical evidence); knowledge (such as using a different
definition of species to that used in biology, and inconsistency of creationist propositions with other accepted science knowledge; purpose (in seeking to demonstrate the match of religious text with contemporary empirical data); context (in rejection by and of accepted, accredited authorities in relevant fields, the social context in which it arises, and the lack of appropriate qualifications of most creationists); activity (in being unable to sustain predictions or empirical tests of claims); and structure (in that creationist claims are inconsistent with highly successful laws and theories).

An objection to this is that, in Kuhn’s characterisation of science, a new paradigm can emerge when sufficient empirical data fits a different theoretical construct better than the existing construct. On this basis one could argue that special creation may simply be an alternative paradigm to evolutionary theory. Thus a mismatch between different propositions of knowledge or lack of endorsement by the existing scientific community (context) alone may not be grounds for dismissing special creationism. However, a multidimensional characterisation is more robust than this, and by considering the multiple dimensions of science one can make a curriculum decision more clearly. This is Archer’s argument. He appeals to a scientific belief system that requires not only naturalistic explanations but also empirical evidence as characteristic criteria for judgments. In turn, these entail empirical activities, consistency with other empirically justified theories and statements of law-like regularities, characteristic purposes and so forth. These are suitable matters for curriculum developers to consider.

3.2.2 The impact of citizens’ rights on this curriculum issue

We have noted in Appendix B.1 on context the influence in (mainly) the US of citizens’ rights as part of science-in-society debates. This brings a different set of pressures to bear on the curriculum: the issue is that individuals or groups of citizens are curriculum stakeholders and have a right, because of their citizenship, to have a say in the content of the school curriculum. This is consistent with the changes, noted above, in some curriculum goals towards increased choice and diversity, in a number of western (and other) countries including Australia. Individual choice of curriculum content can thus, in
one sense, be seen as an extension of individual choice of school system, school or school management. In another sense, choice of curriculum content could be characterised as the what of school education, and choice of school or management structure a question of how. We must ask, first, are there grounds for opposing the rhetoric of citizens’ rights to choose curriculum content, and second, if so, what are they?

There are grounds for questioning, but not opposing, the rhetoric that citizens have a right to choose the content of the curriculum, in the societies we have been discussing. The present thesis has set as its context the mainstream curricula in contemporary, western, pluralistic democracies, in which citizens are able to express their views about school curricula among other things. The pertinent question here, however, is how these rights are argued or opposed concerning the nature of school Science. To this there are several answers, because although the present thesis is clear in arguing for a multidimensional school Science, we have yet to address the question of how and by whom relevant decisions could be made.

One ground for questioning the right of citizens to determine the curriculum is the nature of the view being expressed. If a citizen claims to be making a statement about the nature of science, then that statement must be open to scrutiny, and the present thesis argues that this is best done using a multidimensional characterisation of science in some sort of open forum. The present thesis has argued that the nature of science cannot be determined by one making an individual and arbitrary decision about some dimension of it: the nature of science is complex, multidimensional and not prescribed by any particular individual or group. Judgements about the views expressed by individuals or groups must be made using a characterisation such as proposed by the present thesis, that is grounded in public, scholarly statements about science.

Another ground for questioning this right is the locus of expression: the interaction of citizens’ rights and the school Science curriculum turns on where and how these rights are expressed in the curriculum development process. This right is manifest in different ways in different countries: individualism as an ideology is strong in the US, but less so in Australia and elsewhere. It may be enacted by bureaucrats and politicians acting on behalf
of citizens, by citizens participating in large-scale, public forums set up for just such involvement, or by citizens acting singly or in small groups. In Australia, for example, there are far fewer school systems than in the US, and in NSW citizen involvement is expressed formally but indirectly through a statutory board that is responsible to the elected government. These factors have the effect of making education systems more responsive to high level policy decisions and less to individuals and small groups: citizen choice, therefore, operates indirectly on the school curriculum as part of larger decision making processes. It is not clear that larger forums necessarily lead to better decisions, but pluralistic democracies are predicated on open and accountable decisions. Education systems should be able to show that the curriculum development process is open and accountable, and that there should be mechanisms for citizens to make meaningful and informed contributions to the process. Any subsequent legal actions should have to take into account that such contributions were duly allowed and considered in open and informed discussions. The present thesis provides a framework that would promote such discussion.

The right of citizen choice also turns on the nexus between rights and responsibilities. Complete freedom of expression results in anarchy and the restriction of individual freedoms through the unfettered actions of others. In pluralist democracies rights come with responsibilities, including responsibilities in curriculum development. Science is included in the curriculum because the goals of science education, such as science as worthwhile knowledge and a significant discipline, include both personal and social benefits. The present thesis has argued that the nature of science as knowledge and a discipline is complex and multidimensional; to appreciate the nature of the dimensions and their mutual interactions is to have a robust understanding of science. For example, the view of curriculum as a rational enterprise, that rose to prominence in the 1980s in Australia and other countries, argues that it is inadequate to satisfy the needs of the state simply by serving the needs of the individual: that individuals need to be educated to the highest level for the interests of the state, not for themselves (Ruby 1991). The present thesis argues further that it is so worthwhile that citizens should have a more robust understanding of it,
Chapter 12: Conclusion

and how it affects their lives, than traditional, narrow, characterisations have allowed. This argument, then, becomes a variant of the notion that with rights come responsibilities. The right of citizens to participate in decisions about how science and technology affect their lives brings with it a responsibility for those citizens to be as informed as possible. If citizens, as a society, wish to be able to participate in the decision-making of that society, which increasingly includes decisions calling on a knowledge of science, then citizens must be appropriately educated. If citizens decide to devote curriculum time to something called science, then it should be characterised robustly - well grounded in its literature, and that is the point where citizens' rights are enacted. The weaker version of this argument is that if societies want their citizens to be prepared to make informed decisions, they have a responsibility to ensure, and even require, their school systems provide appropriate curricula. The stronger version is that individuals bear this compulsion to complete such an education, a position more contestable in pluralist democracies.

Another matter that arises in the creationism/evolution debate, although not restricted to it, is the flow-on effect of allowing some non-science into the science curriculum. This is a version of the 'slippery-slope' argument, which has been used in legally comparable contexts:

A slippery slope argument is a kind of argument that warns you if you take a first step, you will find yourself involved in an irreversible sequence of consequences, speeding faster and faster towards some disastrous outcome. A good example was the argument used to support the majority opinion in the recent US Supreme Court decision not to ban burning of the American flag as a criminal act. Justice William J. Brennan, Jr argued that any ruling to ban physical desecration of the flag would lead to further cases that would 'enter territory having no discernible or defensible boundaries'. Wouldn't the court then have to consider prohibiting the burning of state flags, or the Constitution? Justice Brennan worried that in order to evaluate these choices, the court would end up imposing its own political preferences to suppress all kinds of unpopular protests. This kind of outcome is obviously dangerous in a democratic country where freedom of speech is important. (Walton 1992, p. 216)

Of course, when used without sufficient justification, a slippery slope argument can simply be a rhetorical tactic to scare people from making a decision, but just as clearly it can be a valid technique for pointing out the consequences of a potential action (Walton 1992).

This is the argument underlying some objections to special creationism. For example, Archer (1986) has argued that to let special creationism into the science curriculum as
science is to let in a non-scientific world view or belief system. If so, this would be unjust in a pluralistic democracy, in not also admitting all other religious belief systems, particularly since the fundamentalist special creationism is not a mainstream religious belief in western countries. The argument is then in danger of sliding down the ‘slippery slope’:

Were that the only logical consequence, maybe real science would just be able to hang in there. But along with the more conventional belief systems of other mainline religions including Aboriginal Dreamtime cosmologies, remember that waiting impatiently just outside the door, with every bit just as much right to demand time in the science classes (as long as scientific methodology is no longer required for an idea system to be regarded as science), are the astrologers, the diviners, the faith-healers, the psychics, the fork-benders, the astro-projectionists, the geocentric fundamentalists who know that the earth is the centre of the universe around which the sun and all other heavenly bodies rotate, the growing numbers of flat-earth fundamentalists who know that NASA’s pictures of a round earth taken from outer space were a deliberate hoax ... and undoubtedly many other groups would have an equivalent right to demand equal time in science classes. This ‘fair-go’ consequence must surely follow if we encourage the teaching of even just one untestable religion in school science classes. (Archer 1986, pp. 32-34; emphases in original)

Archer here draws attention to what he, and the present thesis, interprets as belief systems. The argument is that science is characterised partly by a methodology and belief system, but to compare science simply with other belief systems is to introduce a relativism that ignores the other dimensions of the character of science. Were the school subject to be called Belief Systems, then one would justifiably compare scientific, religious and other belief systems. But the subject is Science, and therefore should make clear that the belief systems that characterise science do so because of both their own contents and their combination with the characteristic activities, purposes and so forth. The implication of the court decision mentioned above is that there are also problems with citizens’ rights if a decision is made that will lead indefensible and undemocratic decisions about the curriculum: to admit one means that in fairness we admit all comers, with the result that no-one can study what was

9 Eisner (1992) has noted that ‘curricular ideologies derive from what might be regarded as Weltanschauungen - worldviews’ (p. 302), just as we have noted in most post-positivist views of science. Curriculum is self-evidently an expression of human interests and activity, and very often explicitly identifies a particular world view. Also significant are the world views embodied in the belief systems of individual students, again as we have mentioned. Students’ own belief systems must be addressed by the curriculum if students are to challenge their own, implicit beliefs with belief systems characteristic of science. The implication for the science curriculum is that it must recognise and make clear the worldviews it promotes, and address the worldviews of students in its implementation.
originally intended to be science. Religious belief systems may well have a place in the school curriculum, but not as science: they are untestable empirically, entail non-naturalistic beliefs, are not recognised as scientific by the science community, and so forth. Their place in the curriculum has to be argued separately, and this is beyond the scope of the present thesis.

3.2.3 The impact of the emotiveness of religion (and science) on this curriculum issue

The other complicating factor in the creationism/evolution debate over the science curriculum is the emotiveness of both religious beliefs and science. The emotive character of debate about religious beliefs manifests itself here in the claim by literal creationists that to reject their particular beliefs is to reject all belief in God. The tension arises from opposing, strongly held and strongly defended belief systems. There are considerable theological and well as metascientific arguments that apply here, but we will consider briefly only two here.

The first is the claim that a scientific belief system entails the rejection of God. This is generally a curriculum issue only where the curriculum goals arise from particular religious orthodoxies. In this case, the objection to science is often cast as another ‘slippery slope’ argument: that religious belief is based on a particular, literal interpretation of religious text (the Bible in this case, but the Koran or other writings in other contexts), and that denying one tenet such as an account of creation leads to denying other tenets and any belief in God. It is not an issue where the curriculum goals do not arise from religious orthodoxies, or where the religious orthodoxy finds no conflict with science.

The second argument is that most religious orthodoxies - most mainstream religious belief systems in western countries - have no substantial conflict with science. We noted above that the legal challenge to the 1981 Arkansas law was mounted by a coalition of civil libertarian and mainstream religious groups, against the state education system whose expert witnesses were mainly literal creationists. This shows that the evolution/creationism debate is complex, and not simply, or even, a conflict between science and religion. It has just as much to do with clashes between different religious belief systems:
To see that this conflict [between science and religion] is still with us today we have only to look at the clashes between science and the more rigid systems of religious belief, such as the ‘fundamentalist’ branches of Islam or Christianity, which insist on the central importance and infallibility of the Koran or the Bible. In recent years there has been a surprising growth of fundamentalist religions particularly in the USA. The Southern Baptists, Latter-day Saints and Seventh-day Adventists, have been gaining ground at the expense of the less literally minded among the Methodists, Episcopalians, Presbyterians, Disciples of Christ and Northern Baptists. (Hanbury Brown 1986, p. 155)

For Hanbury Brown, the historical clashes between science and religion arise when the limitations of both science and religion are not understood:

In principle the solution is deceptively simple; all we have to do is to recognise which questions can be properly answered by science and which questions by religion. Only by making sure that they both recognise their own limitations can we maintain their mutual respect, and at the same time prevent conflict between these two ways of interpreting this mysterious world.

Pope John Paul II pointed out the importance of recognising these limitations when he said in his address to the Commission re-examining the Roman Catholic Church’s treatment of Galileo:

‘One thus perceives more clearly that Divine revelation, of which the Church is guarantor and witness, does not of itself involve any particular scientific theory, and the assistance of the Holy Spirit in no way lends itself to guaranteeing explanations that we would wish to profess concerning the physical constitution of reality. It is only through humble and assiduous study that the Church learns to dissociate the essentials of its faith from the scientific systems of a given Age, especially when a culturally influenced reading of the Bible seemed to be linked to an obligatory cosmogony.’

(Hanbury Brown 1986, pp. 154-5)

We have noted earlier in the chapter on belief systems the long history of thinking about the relationships between God, Nature, and the role of science, and that many well-known names in the history of western European science, such as Copernicus, Galileo, and Newton, had strong religious beliefs and, often, the backing of the Church. It is not necessary here to explore the details of developments in theology, especially those in the twentieth century, to be able to conclude that belief in evolution as a natural process does not preclude a belief in God. Rather, belief that the two are mutually exclusive has as much to do with competing religious beliefs than with science and religion, and in this respect the emotiveness of the creationism debate bears much of the character of other conflicts between competing belief systems, such as intra-scientific, inter-religious, inter-racial and political disputes. The present thesis interprets Hanbury Brown’s solution, that we recognise the questions answerable by science and religion, as applying a multidimensional
characterisation of science, in particular here the role of belief system and context in characterising science, to establish an agreed boundary between science and religion for the purpose of determining curriculum content.

The emotiveness of religion as an issue in the science curriculum, expressed as concern that science violates the expression of religious beliefs, is also related to the emotiveness of science, expressed as concern about the role of science in societal changes. In this respect the certainty offered by some religious beliefs, and in particular fundamentalist religious beliefs, offers a sense of security amidst increasing social complexity and change. Various commentators have argued that the rise of various forms of fundamentalism in recent decades is a response to increasing social uncertainty (for example, Hanbury Brown 1986, p. 157; Strahan 1987, p. 11). This response is part of a wider phenomenon, the rise of anti-science beliefs, a point noted in the discussion of Venezky, above, and in the companion chapter on context and Appendix B.1. This also affects the public understanding of science, whose relationship to the science curriculum is discussed in part (e), below.

For the present thesis, the response to emotions like fear or loathing is not ignorance, but education. Thus a science education should not be an indoctrination into an uncritical acceptance of any and all claims by scientists, but rather the development of a critical appreciation of the multidimensional character of science. Such a critical appreciation would enable the citizen to examine the costs and benefits, the assumptions and implications, and the judgments and actions entailed by various claims made in the name of, or against, science.
3.3 Conservative versus progressive (right-wing versus left-wing) views about the curriculum

Another debate that affects decisions about curriculum development, including the science curriculum, is the periodically prominent debate between conservative and progressive curriculum stakeholders, including academics, policy makers, educationalists and others. This debate has become more prominent again during the planning and writing of the present thesis, as shown by the international shifts in education policy in the 1980s and 1990s, mentioned above (Purpel & Shapiro 1995). Some commentators refer to this as a clash between the political left and right. In this view, for example, literal creationism is widely associated, particularly in the US but also in Australia, with conservative religious and political groups that express a range of conservative ideologies such as 'the sanctity of marriage, the family, male superiority, parental authority, corporal (and often capital) punishment, and strong government' (Strahan 1987, p. 11).

In another view, as noted above, the curriculum is characterised as a rational system for improving national or societal goals, by groups from across the political spectrum:

[Intensification, assessment and demands for accountability could be seen as new but more particularly, they are 'blue'. They reflect the ascendancy of conservatism as the dominant political philosophy influencing education both in terms of government ideology and in community acceptance. Sometimes this is ascribed to the 'New Right'. This simple claim masks more complex shifts in the influence and power of political ideas. The neo-conservatives have absorbed, endorsed or generated many 'populist critiques of curriculum reform, professionalism and bureaucracy' and used them to support wider concerns about the failure of the state to maintain standards and discipline in schools and society. The implicit demand for a strong state role attracts even broader support encompassing traditional left-wing groups concerned about inequities produced by differential curriculum offerings (Quicke 1988). This conservative influence crosses traditional party division. Labor governments in New Zealand, Labor Governments in Australia, (federally and in Western Australia and South Australia) and socialist governments in France and Portugal have all adopted relatively instrumentalist policies on education. (Ruby 1991, p. 22)10

To some extent then, and in an educational context, traditional notions of a political left and right have become less discernible, but in the significant respect that the policies generally

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10 Ruby's analysis has held since being written, as in the subsequent Labor governments in NSW and the UK, which have broadly maintained the policy shifts begun by the conservative predecessors.
have become more instrumentalist, more explicitly tied to national economic and other political goals, and with greater emphasis on choice and less on equity.

With these changes have come other ‘conservative’ shifts, in particular shifts in academic argument and its representation in political and media contexts. Some of these can be classed as attacks on political correctness, or PC:

The issue of and charges against PC have indelibly marked the terms of political debate and commentary in the US. Whether or not PC actually exists or if its an accurate charge, the rubric of PC has come to define a broad spectrum of liberal-left positions. Affirmative action, deconstruction, feminism, and multiculturalism are all conflated under the banner of PC. And the aspersion of PC has become a shorthand way to dismiss these positions out-of-hand, as ridiculous or tyrannical, shortcircuiting any sort of more elaborated debate or discussion. (Williams 1995, p. 2)

This debate - the so-called PC Wars - is relevant to the present thesis because it includes debates over the characterisation of science. Included in what Williams calls the broad spectrum of liberal-left positions are critical analyses of traditional characterisations of science as internalist, objective, value-neutral, and so forth. They are opposed by conservative thinkers who characterise post-modernism, feminism, multiculturalism and other liberal-left views as an amalgam of arguments that are weakly considered and not politically neutral. This debate forms part of the e/i distinction, discussed earlier in the companion chapter on context and Appendix B.1; Bunge and Latour were mentioned as examples of largely opposing views of science. This is particularly interesting for any discussion of the characterisation of science for the school curriculum because the representation of science seems to be one of the more newsworthy elements of the PC Wars for the popular press. Thus Gross and Levitt’s 1994 book, Higher Superstition: The Academic Left and its Quarrels with Science, and the later text The Flight From Science and Reason (eds Gross, Levitt & Lewis 1997), have attracted press attention that generally supports their attack on studies of science, technology and society, rather than critiquing and clarifying the opposing views. For example, Sandall’s (1996) review of Gross and Levitt, published in The Weekend Australian newspaper, was entitled The Rise of Irrationalism: the title gives the tenor of the review. For the present thesis, which addresses the school curriculum rather than a particular metascientific standpoint, this is yet another metascientific argument that is grist for the mill. However, it is mentioned here as an
example of a debate in the public domain that can affect argument about the nature of school Science: clearly, the readership of Sandall’s review of Gross and Levitt would be far larger and broader than the readership of Gross and Levitt’s original text, and indeed a scholarly rebuttal to Gross and Levitt such as in *Science Wars* (ed. Ross, 1996).

What are curriculum developers to make of such a debate? The response of the present thesis to such a book review in a broadsheet newspaper is that one would expect the newspaper’s readership to be able to make some sort of informed analysis and judgment of the article. This should take into account that we are speaking here of a general newspaper, not a scientific journal for a specialist audience, so that we should expect that any particular article would strike the interest of a reasonable proportion of the readership. Newspapers, after all, are not in the business of running items that very few people will read; journals at least make some concessions here. Our reader, then, should have some understandings of fundamental scientific concepts, but this alone is not enough: both sides appeal to the same science knowledge. The reader should also be aware that different people and groups construe, or characterise, science in different ways, and that many of these views provide useful, though different, insights into science. Thus, for example in Appendix B.1 on context, we have seen than a number of views caution against extreme internalist and externalist characterisations of science, and that Shapin is critical of much e/i debate because opponents have frequently attacked the extreme positions of opponents to make their position indefensible. Sandall, for example, seems to assume a logical positivist view of science:

> A stuffy concern with ‘contradictions’ - we are told - is typical of those unable to break with Baconian science and logical positivism - that is, with science and logic. (Sandall 1996, p. 21)

There is no mention that received views of science, logic and rationality, change from time to time, and that in the late twentieth century there is no single, agreed, metascientific interpretation of these terms.

This is not to argue a complete relativism: we have noted and accepted cautions of extreme views of the sciences. Rather, these issues are complex and cannot be reduced simplistically; a multidimensional view of science helps to represent and understand this
complexity. Thus the reader should be aware that these characterisations appeal to multiple, interactive, dimensions of science: knowledge, activity, purpose, structure, context and belief system. This provides a framework on which to base an analysis and comparison of characterisations.

Thus, for example, the critical reader would question Sandall’s frequent use of the term *irrationalism*. Given contemporary metascientific analysis, Sandall’s argument is weakened by not identifying that rationality is defined in various ways by various groups, his own assumptions about rationality, and why he does not make this clear. The critical reader, however, would concur with Sandall’s point that metaphors are used in science to the extent that they are useful; the only question is whether Sandall (or Gross and Levitt) have accurately represented Harding’s critique of gendered metaphors in science. Finally, the present thesis makes a qualified endorsement of one of Sandall’s (and Gross and Levitt’s) conclusions about the state of science education:

> Modern irrationalism is already having a devastating effect on science education: ‘Many students in lower-level science courses are not only ignorant of science but are ignorant as well of the fundamental frame of mind, the attitudes, the intellectual rhythms needed if one is to acquire useful knowledge.’ (Sandall 1996, p. 21)

The present thesis interprets and supports Sandall as arguing that students need to have a more robust and multidimensional understanding of science. However, the support of these remarks is qualified in several respects. First, Sandall makes unsubstantiated assumptions about *irrationalism* and *useful knowledge*: the present thesis has shown that both of these concepts are interpreted variously, and when used the intended meaning needs to be made clear. Secondly, Sandall’s concern about the (unspecified) *ignorance of students in lower-level science courses* is not confined to just students doing those courses; the present thesis has shown that dissatisfaction and mis-perception are widespread across the spectrum of students. Thirdly, Sandall makes a logical error of the sort he criticises in making an unsubstantiated claim about widespread irrationalism and then linking it causally with science education; this is sloppy. Fourthly, surely the point of a science education is that it enables citizens to address the very controversies about science that concern Sandall, Gross and Levitt; the present thesis indicates that a science education of the very sort Sandall seems to advocate could not do that.
In summary, disputes between conservative and progressive ideologies are just one example of many possible public disputes concerning science and, as we have seen in the view of curriculum as a rational process, notions of political left and right can be blurred in education policy contexts. In response to such conflicts there are three points to be made here about the nature of school science. First, a science education should enable students to make informed contributions to such conflicts, even if in a limited sense. Secondly, the science curriculum should provide a characterisation of science that endures beyond a particular argument that is influential for just a year or a decade, or within a particular locale. Thirdly, a multidimensional characterisation of science is best able to support such an approach.
3.4 The contribution of science education to the national economy

We have noted earlier that there has been, during the 1980s and 1990s, in Australia, the US, the UK and other western, pluralist democracies, a shift in educational goals to emphasise the national benefits of science education. Thus, a range of policy goals increasingly characterise worthwhile knowledge as that which meets broader social and national goals such as: economic advantage; the improved efficiency of the curriculum as increases in the measured outcomes of state-defined goals and decreases in the costs of this process; and the improvement of measured outcomes of the student cohort. This is consistent with the discussion, in the companion chapter on context and Appendix B.1, of the nexus between science, government and industry, which emphasises the utilitarian and socio-political characteristics of science, especially the scientific development from the mid-twentieth century:

Science, technology, and their applications are a ubiquitous part of the world marketplace. In response to the United States' need to remain competitive in a global economy, schools are called upon to provide programs in science that engender scientific literacy in all students. (Simpson et al., 1994, p. 231)

Several questions arise from assertions like these. What is (or can be) the contribution of a robustly characterised science education to the national economy? What is the role of a robustly characterised science education in meeting utilitarian curriculum goals? What is the effect of adopting utilitarian curriculum goals on other science curriculum goals? We will address each of these issues here; the question of scientific literacy is dealt with in section 3.5 below.

It is a reasonable expectation that a pluralistic democracy should be able to set a range of curriculum goals that justify the place and nature of science education in the school curriculum. For example, it is legitimate that the school curriculum should provide a suitable grounding for, and indeed foster, those with the potential and interest in pursuing further studies and careers in science and technology. This is a means of a society ensuring an adequate supply of scientific and technological expertise that confers economic, social, national security and other benefits to that society. It is also legitimate that the school
curriculum should provide a suitable grounding for, and indeed foster, scientific literacy in all students, as future citizens. This is a means of a society ensuring that its citizens can express their democratic rights by participating in informed decision making. The public understanding of science has broader implications than just for the national economy, a point addressed specifically in section 3.5 below.

However, science education is particularly valued by current policy elites because it supports the scientific development that underpins the national economy as well as other social benefits, such as health improvements. Of course, this is not to endorse an uncritical indoctrination into science: the present thesis has argued that a multidimensional characterisation of science is more likely to lead to an ability to weigh up both costs and benefits and to evaluate competing claims made in the name of science. This is consistent with the notion of a pluralistic, participatory democracy. There is no single, unified benefit of economic development to society. Rather, the overall economic benefit is the sum of many and varied individual developments, some of which represent sectional and short-term interests. Citizens need to be able to participate in decisions about competing claims for economic benefit, and other benefits, such as issues of health, quality of life and ethics, for example.

A multidimensional characterisation of science provides a better preparation for all these issues than does a traditional, narrow characterisation of science. There are several arguments for this. First are the characteristics of science that make it economically useful. For example, we have discussed in the companion chapter on context and Appendix B.1 the inextricable links between much of contemporary science, government and industry. We have also discussed, in the companion chapter on knowledge and Appendix B.6, the rapid and increasing development of science knowledge, partly due to scientific activity meeting instrumental (government and industry) purposes. Thus students should recognise that a considerable amount of scientific activity and knowledge arises from political and industrial purposes and contexts, and not just from the disinterested, intellectual curiosity of gifted individuals that receive most mention in school Science. Economic and other benefits
have, in the past and probably also in the future, flowed from both applied and pure research.

Second is the argument that national economic development requires a rigorous grounding in science for at least the potential scientists and technologists. That is, the science curriculum should provide a sound preparation for tertiary science and technology studies. The debate about the rigour of school Science was discussed in section 3.1 above, but we can apply that discussion also to the justification of school Science by national, economic goals. That is, a multidimensional school Science is not only a more robust characterisation, but likely to be more meaningful to students. It is therefore more likely to increase student participation when, as we have mentioned, enrolments are declining in the senior sciences. It is also more likely to raise the standard of learning outcomes. Thus, for example, the companion chapter on knowledge showed that scientific knowledge implies personal understanding and not just recall of data, definitions and information. This characteristic, together with the constructivist science education literature on children's misunderstandings, strongly implies that the science curriculum should emphasise soundness of understanding rather than merely covering many topics. This point is made almost routinely by science educators, and almost as routinely ignored in the implementation of the science curriculum (Fensham 1995). The rapidly increasing body of science knowledge is therefore not an argument for covering more content per se, but for understanding the scope of science knowledge and examples of recent scientific developments. Efforts by science curriculum developers to allow plenty of scope for teachers to represent the vastness of science knowledge, and to select from this scope that which best suits their students, are commendable. However, clearer efforts must be made to prevent teachers from feeling obliged in some way to cover as much as possible, and instead to select the most fruitful and develop in students sound understandings of it. A multidimensional framework assists curriculum developers and teachers to make informed selections.

Third is the body of criticism of traditional approaches to science education. For example, we have mentioned the extensive literature dealing with the ineffectiveness of
traditional science education in dealing with children's prior conceptions. This literature pays particular attention to the understandings children have of scientific concepts, and so addresses the character of scientific knowledge as understanding, discussed in the companion chapter on knowledge and Appendix B.6. Again, this indicates that the science curriculum should emphasise science knowledge as understanding rather than superficially covering large numbers of propositions to be recalled. We have also noted criticisms, such as Matthews (1994) above, that 'the more science students do, the less they like it' (p. 33). This is consistent with arguments that traditional science education is unappealing to many students: that it does not adequately redress unappealing stereotypes of science and scientists; that the acontextual, positivistic character of school Science knowledge removes the appeal of human interest and relevance; that it does not address conflicts with students' own belief systems; and that it does not address anti-science sentiments in the community arising from issues like pollution, food additives and nuclear radiation. That is, not only does a traditional science education fail to address issues that interest children and adolescents, but the approach discourages able students from pursuing higher levels of science studies. The present thesis argues that this arises from the distorted characterisation of science presented in much school Science. This argument is supported by claims that science should be studied in its historical, social and philosophical contexts (Lowe 1987b; Matthews 1994).

The caveat on this line of argument is that science is characterised by more than its industrial, economic and political uses, and that to justify science purely with its economic or other utility is to distort, yet again, its characterisation. Thus, the criteria for scientific judgement - demonstration of experimental support or refutation, logic of argument, and so forth - are different from the criteria for economic judgement. For example, the economics of producing a polymer arise from different criteria to those by which we judge the purity of a sample or its health risks. Also, the scientific community strenuously resists attempts to characterise scientific research solely as applied: the theoretical or economic usefulness of a scientific development is often not appreciated until well after the event.
Finally, much of the literature describes an inherent worth in studying science for its own sake, as a significant expression of the human condition:

In the end, the purely instrumental utility of scientific knowledge may be less important than the wider value to be gained from being acquainted with science as one of the great expressions of the human spirit. Science has been and continues to be one of the noblest achievements of mankind [sic]. From a humanistic point of view, its attainments are on a par with great achievements in art, literature, and political institutions, and in this perspective, science should come to be known for the same reasons as these other subjects. (Trefil 1987, p. 151)

It is a reasonable goal of a society that it should prosper, and that its science curriculum should contribute to this. However, it is a distortion of science, and potentially a great distortion in school Science, to select only those dimensions of science that are narrowly utilitarian in the short term. Furthermore, it is a distortion of the science education required by a scientifically literate public, and the public understanding of science.
3.5 Scientific literacy and the public understanding of science

The multidimensional characterisation of science proposed by the present thesis, and its focus on the science curriculum for all students, has implications for debates about the scientific literacy of citizens, both in their own right and as a basis for judging models of science literacy. The significance of the public understanding of science and science literacy as educational goals cannot be overstated. We have seen in Appendix B.1 that citizen groups have already gained considerable momentum, especially in the USA but also elsewhere. This has led some commentators to claim that the scientific community has started to lose its political clout:

Questions of power, responsibility, and accountability continue to drive disputes. But controversies have also changed over time. In the 1970s and early 1980s, they represented the so-called crisis of authority that prevailed in the political life of that time (Salomon 1977). And they indicated the willingness of local groups to mobilise against decisions that affected particular interests. By the end of the 1980s, protesters increasingly framed their attacks on science in the moral language of rights.

By 1990 Yaron Ezrahi, in *The Descent of Icarus*, suggested that the attacks against science represent a major conceptual change in the role of science in society: "In the closing decades of the 20th century, the intellectual and technical advances of science coincide with its visible decline as a force in the rhetoric of liberal democratic politics" (Ezrahi 1990, p. 13). (Nelkin 1995, p. 447)

Nelkin’s point can be interpreted as these citizen groups rejecting a purely internalist context for science, and identifying additional or alternative beliefs, criteria and purposes of science.

The combination of these critiques of public understanding of science, however science literacy might be defined, is a condemnation of the general science education received by the citizens studied: that the traditional emphasis on knowledge but not understanding, and on activities restricted to a notional set of experimental processes, has been inadequate.

We have argued above that the notion of rigour does not apply only to narrow, instrumentalist views of science education for potential scientists and technologists, not the least reason being that with the increasing specialisation of science even scientists cannot claim current expertise in areas outside of their own specialisation. In brief, the present
thesis claims that a multidimensional characterisation of science provides a more rigorous and appealing curriculum as preparation for participation in a pluralistic democracy that increasingly requires public participation in scientific and technological matters. Appendix B.6 on knowledge reviewed research on the public understanding of science; the present section seeks to apply the findings of this field to the school curriculum. In particular, it draws attention to those parts of various literatures - science education, public understanding of science and science literacy - that address scientific literacy and school education.

3.5.1 The public understanding of science (PUS) vs scientific literacy

At this point, it is important to note that the terms public understanding of science, and scientific literacy of the public are not clearly distinguishable. Both are interpreted variously, and sometimes interchangeably, in the literature and in more general contexts. However, there is an important distinction between uses: a narrower sense that essentially means knowledge, and a broader sense that means or implies more than just knowledge. Also, many conceptions and analyses of PUS and scientific literacy are flawed. We will discuss these uses and flaws using some examples.

Flaws in traditional measures of PUS and scientific literacy

a) Unidimensional measures of knowledge are inadequate

We have noted in Appendix B.6 that much of the research on the PUS uses the narrower meaning of knowledge recall and comprehension. This is flawed in several respects. First, simple measures of propositional knowledge are inadequate:

Science, technology, and their applications are a ubiquitous part of the world marketplace. In response to the United States’ need to remain competitive in a global economy, schools are called on to provide programs that engender scientific literacy in all students. The traditional meaning of scientific literacy - an understanding of the norms of science and knowledge of major scientific constructs - is no longer adequate. Students today should be aware of the impact of science and technology on society and the policy choices that must inevitably emerge; that is, they must acquire favourable attitudes toward organised science knowledge. According to the best available evidence, only 7 percent of adults meet these standards (Miller 1983).

Knowledge acquisition reduces illiteracy, but efforts to reduce illiteracy may fall short of the mark. Becoming literate does not guarantee widespread participation in the scientific enterprise. Programmatic efforts to reduce illiteracy through
knowledge acquisition alone may do little more than produce persons who are scientifically aliterate; that is, they possess knowledge but choose not to act on their knowledge. For the general public to be attentive but indecisive is ominous for a nation likely to become increasingly dependent on public support to sustain an economy committed to science and technology.

To produce scientifically literate graduates - persons who understand the scientific approach, basic scientific constructs, and science policy issues and exercise their civic responsibility - science teachers, educators and policymakers must insist on the development of favourable attitudes toward the use of science along with the acquisition of knowledge as benchmarks against which the condition of science education is assessed. (Simpson et al., 1994, p. 231)

The present thesis interprets this as a multidimensional characterisation. Thus Simpson et al., characterise science literacy in terms of persons who understand (knowledge, context), the scientific approach (activity and purpose), basic scientific constructs (structure and knowledge), science policy issues (knowledge, context and purpose), exercise their civic responsibility (activity, context, belief system), science teachers, educators and policymakers (context), development of favourable attitudes toward the use of science (activity, belief system, context, purpose), acquisition of knowledge (activity, knowledge), and benchmarks (criteria as an element of a belief system). Accordingly, discussions of science literacy tend to make more complex (multidimensional) characterisations, arguing for re-definitions that address the inadequacy of merely acquiring propositional knowledge.

Some more recent, critical, studies of public understanding of science would question Simpson et al.,'s use of the term favourable attitudes toward organised science knowledge. An uncritically favourable attitude would be consistent with attitudes arising from an indoctrination rather than an education, as in a predisposition to accept the claims of the science community. It would not equip citizens for contesting science claims in the public domain, or for evaluating the competing science claims of vested interests. It is the interpretation frequently used in traditional studies of the public understanding of science (Wynne 1995), as discussed in the companion chapter on context and in Appendix B.1. These traditional approaches characterise public-science issues as a deficient public understanding of an unproblematic and unscrutinised science. Thus some analyses argue that the lay public has neither the interest nor the expertise to participate in disputes within the science community. Others extend this argument to claim that the science in public
disputes is too complex for the majority of citizens and they should not participate in those disputes either:

In the modern world, the supposed complexity and esoteric nature of science policy renders it inaccessible to popular comprehension and thus uncontrollable by democratic decision making. Studies finding fewer than 7% of the American public scientifically literate (Miller 1991) and British attitudes toward science incoherent and inconsistent (Ziman 1991) reinforce the postulate that science is too complex for nonexperts to administer and too subtle for the letter of the law to govern. Political processes developed for the governance of 'simpler' policy problems within the ken of citizens and politicians are in this view inappropriately applied to science policy, where the entry costs - specialised training and facility with an arcane language - are inordinately high. (Bimber & Guston 1995, p. 557)

This, as discussed in Appendix B.1, is part of the argument that science is exceptional because it is comprehensible only to exceptional people.

However, a favourable attitude could also be construed as valuing the collection of evidence and understanding of arguments as part of informed participation. This second interpretation arises more because of the increasing number of science disputes that are not restricted to science communities, and rejects the assumption that science is comprehensible only to exceptional people. In considering the multidimensional characterisation argued in the present thesis, we could extend that to mean citizens also value elements of characteristic belief systems, such as beliefs, assumptions and criteria for judgment including empirical data and reproducible methods, the logical structure of argument, and characteristic purposes of scientific activities, such as the pursuit of empirical data, disconfirming results, naturalistic explanations, and so forth. Further, such citizens would value making a multidimensional critique of published science claims, policy decisions, and so forth, as a means of comparing actual claims with what idealised scientific activity might produce. That is, favourable but not uncritical. Also, the present thesis has argued that science knowledge is so immense and increasing so rapidly that a comprehensive personal knowledge of science is not possible. Thus the public may not act because they choose not to act on their knowledge, but because they are unable to act, whether because they lack the requisite attitudes (such as conviction, scepticism or valuing civic responsibility), skills (such as validating knowledge claims, or public advocacy) or knowledge (such as of relevant scientific principles). Nonetheless, the central tenet of Simpson et al., is persuasive: that knowledge alone - however science knowledge is characterised - does not
equate with scientific literacy, although some knowledge is necessary for literacy, and that particular attitudes and skills are necessary.

b) Flawed assumptions in traditional measures

Secondly, much of the research on public understanding of science collects data based on the twin assumptions of public deficiencies in science knowledge and the unproblematic character of canonical, or received, science knowledge. Both of these assumptions are flawed. Wynne (1995) is critical of approaches to the public understanding of science that either uncritically devalue the belief systems and folk theories of lay individuals, or uncritically fail to address assumptions and risks in decisions from within the science community:

E. Martin (1989) has argued that working-class women reject dominant medical views of menstruation because the whole medical-scientific construction of menstruation represents it, in social terms, as ‘failed reproduction’. This implicit social construction reflects middle-class concerns for working careers and inadvertently denigrates working-class social relations and values. An alternative cultural construction - of menstruation as the very process that creates ‘the lifestuff that makes us women’ is alive and well among working-class women, who more positively value noncareer social relations, including motherhood. (Wynne 1995, p. 376)

Wynne notes that this rejection was despite exposure to received biological knowledge, arguing that it represented a ‘healthy and legitimate resistance to dominant ideologies carried in scientific idioms’ (p. 376). Testing the women’s understanding did not assess their assimilation into the dominant ‘failed reproduction’ characterisation of menstruation. Other examples were nuclear workers who routinely ignored safety warnings at nuclear sites, and hypercholesterolemia sufferers who dismissed warnings about dietary fats:

Laypeople may ignore scientific knowledge because they regard it as irrelevant, even though scientists assume it ought to be central to them ... These authors also noted that survey methods of measuring public understanding of science inevitably reduce ‘understanding’ to simple indices that cannot do proper justice to the complexity of what is being ‘understood’ in real-world contexts. Prewitt (1982) has observed that scientists’ own unreflective social assumptions about what is relevant to lay people are built into scientific knowledge for public communication and, furthermore, into the design of survey instruments to test public understanding. For these reasons, Layton and colleagues (1986) questioned whether such surveys test public scientific literacy or whether, instead, they measure the degree of the public’s social conformity to a stereotype held by scientists of a ‘scientifically literate public’. (Wynne 1995, p. 378)

11 See Appendix B.6.
Thus many of these studies are also flawed where the science community fails to identify its own assumptions, either concerning its knowledge claims or public scientific literacy, or fails to label as subjective and irrational instances where lay people support the scientific community for non-technical reasons, such as significant social relationships, disinterest, unsubstantiated trust, and so forth. The present thesis argues that the notion of scientific literacy needs to take account of the belief systems, purposes, contexts, activities and structures of (lay) public knowledge as well as of accepted science knowledge, in making judgements about science literacy.

Students (and adults) have prior conceptions, folk theories and local knowledge that may be useful to them. Wynne's examples are examples where local, folk theories are used successfully by individuals and groups, where this knowledge may be independent of, or even in conflict with, knowledge accepted by the science community, or at least where these folk theories have not demonstrated universal applicability or accepted 'scientific' validation. Part of the reason for the persistence of prior conceptions is that folk theories are often correct for the individual. Folk theories are frequently situational and may conflict with other folk theories or accepted scientific theories; yet they are often useful to the individual. Thus, in addressing scientific literacy, the science curriculum needs to recognise that children and adults have prior conceptions and theories that are resistant to traditional approaches to science education for reasons that are very sound to the individual. The science curriculum should address the folk theories used by children, as part of improving learning, and the folk theories used by adults, as part of the ways in which citizens confront claims to science knowledge in public issues. This is as a response not only to the immense science education research into children's prior understandings and misconceptions, but also in response to the present thesis which has drawn attention to the role of belief systems as an essential dimension of the science we have judged the children should learn. If a goal of the science curriculum is to produce a scientifically literate society, then curriculum developers must recognise the limitations of the traditional deficit model of public understanding of science, that is, that citizens are somehow deficient in their

12 We have mentioned already the immense literature on children's prior understandings.
knowledge and appreciation of science, while science is somehow unproblematic. There are several implications of this claim.

We have also noted that while much scientific knowledge is unproblematic within the science community, it is by definition problematic within the science community when scientists disagree on approach or interpretation, and is often problematic in public disputes. Examples include: when scientists do not agree on the approach to investigation or the interpretation of results outside the received paradigm; in examples of applied research where commercial or strategic goals influence knowledge claims; and when research has wider, public implications. As we have discussed, in many public disputes both sides may claim the authority of science, and the assumptions, purposes, criteria and contexts associated with each claim can be difficult to clarify. Hence the variety of approaches to studying science controversies, showing that the range of contexts of scientific disputes cannot be reconciled with the simple view that science knowledge is unproblematic (see Martin & Richards 1995). The curriculum must address this if it is to address scientific literacy. In other words, this dimension of science knowledge is better characterised in combination with other dimensions such as context, belief system (substantive beliefs, criteria and assumptions) and purpose.

The notion of scientific literacy seems better fitted to a multidimensional characterisation of science, where literacy is used in its broader sense to mean not just able to read and write, but to mean educated or learned (The Macquarie Dictionary). Thus the scope of science literacy seems better suited to school students than does public understanding of science, and therefore to the school Science curriculum.

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13 Martin & Richards (1995) have argued that it is both possible and necessary to use different techniques of analysis to study scientific disputes within a scientific community and those that include social controversy, even though ‘science’ is involved in both. Some approaches do not assume that science is unproblematic.

14 Shamos (1995) has a pessimistic view about scientific literacy as a goal of science education, because it has failed in the past and no solution is forthcoming. He is more optimistic when the emphasis on knowledge is lessened in favour of attitudes, skills and knowledge of social contexts of science; or what we have called scientific literacy. The present thesis interprets this as a straightforward argument for a multidimensional characterisation of science.
c) Flawed assumptions in what is important

Another aspect of flawed assumptions in measures of PUS or scientific literacy is in what is important to measure. This is the case in making lists of what should be known. A well known example is Hirsch (1987), who attempted to map the content of cultural literacy of US citizens (Cultural Literacy: What Every American Needs to Know), which includes concepts that indicate scientific literacy. Yet, even allowing for Hirsch’s caution that such a list must in some sense be arbitrary and subject to change, there are many curious omissions: AIDS is included, but hepatitis is not, despite their common association in public health literature; gremlins is included, but mouse, either meaning the rodent or the computing technology, is not; Walt Disney and Cecil B. De Mille are included, but Isaac Asimov, Carl Sagan, David Suzuki and other science popularisers are not; theocracy is included but theory is not; the only mentions of law are law of contradiction and law of universal gravitation; neither evidence, experiment, falsify, information explosion nor risk are included. Yet, in the note on the scientific terms included in Hirsch’s list, Trefil claims that in compiling the list of terms for cultural literacy, broader criteria were used for the science terms:

Because there is little broad knowledge of science even among educated people, the kind of criteria used to compile our lists for the humanities and social sciences - for example, Would a literate person be familiar with this term? - simply can’t be used for the natural sciences. The gap between the essential basic knowledge of science and what the general reader can be expected to know has become too large. Our criterion for choosing a science entry has been that the candidate must be truly essential to a broad grasp of a major science. This criterion may not assure true scientific literacy, but it should at least help overcome serious illiteracy. (Trefil 1987, p. 148)

Given the analysis of the present thesis, Trefil’s criterion is hard to reconcile with omissions such as those noted above. It is clear that Hirsch and his team have assumed public scientific literacy to be familiarity with an arbitrary list of key concepts, a strategy that the present thesis finds quite inadequate. The difficulty of making arbitrary decisions about which concepts to include is only one issue in a complex task: the present thesis argues that the scientifically literate citizen would not only have understandings of key concepts, but something of the complexities of scientific knowledge and its interactions
with characteristic activities, purposes, contexts, structures, belief systems. This is consistent with Trefil's general argument for public scientific literacy:

Some of my scientist colleagues are inclined to talk vaguely about the desirability of citizens acquiring the competence to make technical judgements. In reality, the true benefits to be gained from a broad improvement in scientific literacy do not derive from that ability. Scientists who do not specialise in a precise field in which a technical question arises are scarcely better equipped than lay people to reach technical judgements in that field. But all citizens must be equipped to make nontechnical judgements about technical questions.

For example, in the debate over the Strategic Defense Initiative ('Star Wars'), it is a serious error to expect literate citizens, including nonspecialist scientists, to make highly specialised technical decisions. Instead, their education should simply have provided them with the general facts and principles needed to understand the terms of the debate - how a satellite works, what a laser can do, and under what conditions such a system would be likely to succeed or fail. Similarly, in the great nuclear safety debates of the 1970s, all participants had to use the same basic scientific background for their arguments, and the real debate centred on whether the admittedly small risks of accident were acceptable in the light of the benefits. Once basic technical issues are understood, policy questions become ethical and political, not technical. (Trefil 1987, p. 150)

While the general thrust of Trefil's argument supports that of the present thesis, there are some flaws. First, the notion of an issue simply having general facts and principles is ingenuous at best. In issues like the Star Wars initiative or developing nuclear power plants, part of the very debate was the status of information as facts: opponents were suspicious that the information provided to the public came from interests - government and industrial - whose purposes, contexts and belief systems were not disinterested and objective. It is disingenuous to claim, as Trefil does, that all participants had to use the same scientific background for their arguments.

Secondly, of the requirements listed to enable public decisions, satellite and laser are mentioned in Hirsch's list, but not the conditions under which such a system would be likely to succeed or fail. These conditions arise from the belief system used (criteria for judgment), the purposes and the contexts. This is the reason, for example, why the public has been sceptical of the research carried out by tobacco companies on the health risks of smoking. Thus knowledge alone of satellites and lasers is insufficient preparation for decisions about their use in strategic defence; there is more than this.

Thirdly, the boundary work discussion in Appendix B.1 on context showed that it is not clear, especially in examples such as Trefil gives, where technical issues end and policy, ethical, political and other issues begin. The very suggestion of developing nuclear
facilities or strategic defence initiatives is a political and ethical one, especially when
government funds are directed to their research or contracts awarded for their development.
The knowledge produced by the scientists involved will arise because particular research
questions and activities were pursued toward particular goals in particular contexts. Given
different purposes and contexts, different questions would have been pursued, activities
carried out and knowledge produced. Likewise with ethical matters: what is argued to be
ethical in one political context may not be judged as ethical in another. New Zealand, for
example, made a politico-ethical decision to ban nuclear powered ships from entering its
ports, to the annoyance of its strategic ally, the US, whereas just across the Tasman Sea the
Australian government, also an ally of the US, made the opposite decision.

Fourthly, despite Hirsch’s terminology of literacy, Hirsch’s attempt is an example of
the approach we have noted as widely used in studies of the public understanding of
science, that accepts scientific knowledge as unproblematic while problematising public
knowledge.

Despite these criticisms, Trefil’s central argument for teaching for scientific literacy is
sound:

Should we therefore conclude that science education is useless in producing
informed citizens? Of course not. One might just as well argue that because the
details of constitutional law can be understood only by legal experts, it’s not
necessary for citizens to know anything about the Constitution. We understand
broad issues of national law because we have been taught the main principles of
the Constitution and can make broad judgements on the basis of that elementary
knowledge. Similarly, if we gain basic scientific literacy, we can make intelligent
judgements about broad issues of technology. (Trefil 1987, p. 150)

d) Lack of focus on capability

Explicitly in Simpson et al., above, and implicitly in Trefil, above, is the criticism that
mere knowledge is inadequate in modern scientific and technological societies: there must
be some capacity and propensity to act to use, check and develop knowledge. That is, there
must not only be knowledge, but capability. Significantly for the present thesis, this has
included recognition for the role of science education:

More recently, a growing number of science education scholars voiced the opinion
that science education required a rather radical re-directioning. This direction
focuses not on pre-professional training. Rather, its focus is on the
interrelationship of science, technology and society ... These [STS] curricula
stress the importance of decision making in science- and technology-related social issues ... Fletcher Watson (1980) states that 'decision making must be the central and crucial element of future curricula'. Aikenhead (1980) believes that science education must lead to the creation of a 'science critical' public capable of making decisions in science laden social issues. Kahle and Yager (1981) state that 'in addition to assisting students to gain the information on which valid judgements and decisions can be made, science education must prepare them in decision making skills'. Bybee (1980) stresses that 'people need to be aware of science related social problems and should realise that their personal decisions make up larger “social” decisions that can either perpetuate or alleviate social problems'. This perspective is echoed by Zeidler (1982) who claims 'science education ... demands that individuals become informed citizens by maximising the opportunities under which students may have practice and experience in decisions concerning science and social policy'. NSTA (1983) posits that 'courses should provide students with opportunities to develop skills in identifying science-based social problems and in making decisions about their resolution'. (Fleming 1987, pp. 313-4; emphases in original)

These views of science education characterise scientific literacy partly by a capability and even propensity to acquire and apply science knowledge in real contexts. Thus Jevons, for example, has described an interplay between scientific literacy, political literacy and understanding the nature of science:

Three major educational objectives of teaching in the science, technology and society area are identified: scientific literacy, political literacy, and understanding the nature of science. Scientifically literate people are those who are both able and willing to inform themselves on issues with a science or technology content as and when such issues arise. Political literacy is a sense for the interplay of values as represented by interest groups and pressure groups. Science needs to be recognised as a human and social activity, not immune from human and social influences. (Jevons 1987, p. 135)

Implicit in some of the examples given by Fleming, above, and explicitly in the present thesis among others, is that scientific literacy entails some sense of political literacy, as characterised by Jevons, and an understanding of the nature of science. This sense of political literacy, and hence scientific literacy, implies a willingness or propensity to act or to engage productively in real issues.

3.5.3 Preferred models of scientific literacy

This brings us to preferred goals of PUS and scientific literacy. For all the reason of narrow associations of PUS with knowledge acquisition, the present thesis suggests that the term public understanding of science is too problematic as a goal of the science curriculum. On the other hand, the term scientific literacy does not seem to be used in the same pejorative sense, and implies instead some measure of capability rather than
deficiency. The present thesis therefore advocates public scientific literacy as a goal of the general science curriculum, rather than mere public understanding of science. The question that remains is how this scientific literacy can be described or measured for the school curriculum.

There are various models of scientific literacy, including models proposed for goals of science education. General statements may imply a notion of scientific literacy, as by Simpson et al., above, or draw attention to particular science education goals that concern a wider notion of literacy than mere acquisition of knowledge:

In his review of science curriculum developments in, mainly, the US and the UK, Matthews (1994, pp. 29ff) has described several attempts to address science literacy. He noted a variety of definitions, and rejected for the purposes of a general science education narrow, technical approaches to science literacy:

There are many ways to define science literacy: from a narrow definition where literacy is the ability to recognise formulae and give correct definitions, to a more expansive or liberal definition which includes understanding of concepts and some degree of understanding about the nature of science and its historical and social dimensions. There is no one correct definition of science literacy; it is a matter of different conceptions proving their worth for the promotion of particular ends. For schoolchildren, the overarching end is their educational development. The contention of this book is that an expansive or liberal definition of literacy is more conducive to this end than restricted definitions. This argument, as with so many matters confronting science teachers, requires a vision of good education, a philosophy of education. The liberal view of education underpinning this book holds that education generally, and science education in particular, is not just a means of developing 'human resources' so that countries can overcome their balance of payments deficit, or stay competitive with other economies. The latter, economistic view of education, promotes a narrow conception of science literacy. (Matthews 1994, pp. 31-2)

Matthews' criticism, that the recent re-emergence of economic and other instrumentalist curriculum goals works against the goal of general science literacy, is shared by a number of curriculum stakeholders including science educators and scientists, and including the present author. However, as we have noted, the view of curriculum as a rational enterprise has been influential, and perhaps dominant, in many western countries including Australia, since the 1980s. At best, one could claim that in that view, terms like scientific literacy are not central goals of the emergent policy elites, and at worst they are neglected or even considered antithetical. We have mentioned that the large body of constructivist research into children's prior understandings and their effects on curriculum and teaching outcomes
does not figure in the political rhetorics of concern with the educational ‘basics’ and the national, economic benefits of science education. Similarly, political concern with public understanding of science tends to be argued in terms of maintaining ‘standards’, curriculum efficiency and utility than with science literacy. There is a need to assert a robust argument for science literacy as goal of the general science curriculum.

Perhaps the most comprehensive and explicit attempt to formalise the inclusion of science literacy in the science curriculum has, to date, been in the US, notably efforts by the National Science Foundation (NSF), and the American Association for the Advancement of Science (AAAS). In particular, *Benchmarks for Science Literacy (Project 2061, AAAS 1993)* set out a thoroughgoing attempt to set out a rationale for, and stages for achieving literacy, in science, mathematics and technology. It gives the following definition of *science literacy*:

A literate person is an educated person, one having certain knowledge or competencies. But of course the rules keep changing with regard to precisely which knowledge and competencies define literacy - the ability to write one’s name and read a simple prose passage long since having been replaced by more demanding requirements. In today’s world, adult literacy has come to include knowledge and competencies associated with science, mathematics, and technology. Project 2061 has undertaken, in *Science for All Americans*, to identify the knowledge and habits of mind that people need if they are to live interesting, responsible, and productive lives in a culture in which science, mathematics, and technology are central - that is, to describe what constitutes the substance of science literacy.

People who are literate in science are not necessarily able to *do* science, mathematics, or engineering in a professional sense, any more than a music-literate person needs to be able to compose music or play an instrument. Such people *are* able, however, to use the habits of mind and knowledge of science, mathematics, and technology they have acquired to think about and make sense of many of the ideas, claims, and events that they encounter in everyday life. Accordingly, science literacy enhances the ability of a person to observe events perceptively, reflect on them thoughtfully, and comprehend explanations offered for them. In addition, these internal perceptions and reflections can provide the person with a basis for making decisions and taking action. (*Project 2061*, p. 322)

Again, this more complex view of scientific literacy uses a multidimensional characterisation: *habits of mind* (belief system), *ability* (activity, context), *knowledge* (knowledge), and *think about and make sense of*, *reflect*, *making decisions and taking action* (activity), and *to think about and make sense of* and *for making decisions and taking action* (purpose).
In his review of some approaches to science literacy as a curriculum goal, Matthews presented an argument for a robust understanding of the multidimensional character of science:

Paul Dehart Hurd, at the end of the 1950s, advocated a broad conception of literacy that entailed students knowing something of the interrelationship between science and society (Hurd 1958). He has continued to emphasise this theme in publications over the past three decades. In lamenting the failure of the NSF discipline-based reforms of the 1960s to give students a sense of the broader canvas of science, he said in 1987 - in words that HPS advocates can endorse - that:

A measure of scientific literacy is a measure of cultural awareness. The traditional science curriculum leaves students foreigners in their own culture. A problem in bringing about the essential reform of science teaching is that there are too many scientists who are scientifically illiterate and too few philosophers, sociologists, and historians of science and technology who are interested in precollege science education. (Hurd 1987, p. 136)

A still more expansive definition was proposed by the [US] National Science Teachers Association in 1982. It defined a scientifically literate person as one who understands that society controls science and technology through the allocation of resources; who uses scientific concepts, process skills and values in making everyday decisions; who recognises the limitations as well as the usefulness of science and technology in advancing human welfare; who knows the major concepts, hypotheses and theories of science and is able to use them; who distinguishes between scientific evidence and personal opinion; who has a richer view of the world as the result of science education; and who knows reliable sources of scientific and technological information and uses these sources in the process of decision-making (NSTA 1982).

Liberal accounts of scientific literacy are more expansive than professional ones. Liberal accounts contain technical, social and cultural elements. A scientifically literate person should know some science (its content and processes), something about science, and they should have internalised something of scientific procedures and attitudes. Thus we might expect a scientifically literate person to, among other things:

1) Understand fundamental concepts, laws, principles and facts in the basic sciences.
2) Appreciate the variety of scientific methodologies, attitudes and dispositions, and appropriately use them.
3) Connect scientific theory to everyday life and recognise chemical, physical and biological processes in the world around them.
4) Recognise the manifold ways that science and its related technology interact with the economics, culture and politics of society.
5) Understand parts of the history of science, and the ways in which it has shaped, and in turn been shaped by, cultural, moral and religious forces. (Matthews 1994, pp. 32-3)

This is consistent with the analysis given in the present thesis. Matthews goes on to note that the views of science literacy he has given are formal, and do not say exactly what is meant by scientific methods, or values, or interactions with society. Decisions of that sort, he says, are more contentious than general statements of science literacy, and arise in curriculum implementation. This is so, and the AAAS Benchmarks for Science Literacy is
an example of an attempt to set out the desired learning outcomes at various stages of schooling. While that level of specification is beyond the scope of the present thesis, the present thesis does, nonetheless, suggest some of the detail that would 'flesh out' general statements of science literacy.

3.5.4 Towards a multidimensional definition of scientific literacy

Given the discussion of science literacy and public understanding of science, above, the following is suggested as an example of robustly, or rigorously, basing a notion of scientific literacy on the scholarly and refereed scientific and metascientific literature.

A scientifically literate person has a richer view of the world, and is personally empowered, as a result of science education. From this education, such a person will, among other things:

1. have a robust understanding of the multi-dimensional nature of science;
2. have a richer understanding of themselves, others and their environments; and
3. have an enhanced capacity to apply these understandings to themselves, others and their environment.

These three goal sets can be expanded as follows. The scientifically literate person will, among other things:

1.1 appreciate that the character of science is multidimensional, that is, it is characterised by the combination of characteristic knowledges, activities, structures, contexts, purposes and belief systems;
1.2 appreciate the contributions and limitations of science as part of the human experience;
1.3 appreciate that different people or groups distinguish between what is scientific and non-scientific in different ways because of different belief systems, contexts and purposes;
1.4 appreciate the large and expanding scope of science knowledge;
1.5 understand that society controls science and technology through the allocation of resources, education, the characterisation of science in the mass media and other ways;

2.1 understand the major concepts, hypotheses and theories of science;

2.2 have current scientific understandings of self, others and the material environment;

2.3 be able to access and evaluate scientific and other, related, information;

3.1 select and use appropriate and accepted scientific concepts, theories, process skills and values in making decisions, whether in specialist or everyday contexts;

3.2 recognise the limitations as well as the usefulness of science and technology in advancing human welfare;

3.3 judge the reliability of sources of scientific, technological and other information, and use appropriate sources in the process of decision-making; and

3.4 apply the multiple dimensions of science in judging the scientific merit of a claim, such as evaluating results that claim to be scientific, seeking scientific evidence, and distinguishing judgments made on other criteria, such as personal opinion, economic, religious, aesthetic or political reasons.

Note that these statements include the knowledges, skills and attitudes of scientists and technologists in their fields of expertise as well as in public and personal contexts.

Statements such as these could be expanded further using examples given in the present thesis. Note that we expect the scientifically literate person to know where to find sources of reliable information, how to access this information, and to be able to use it. This entails the student, later the citizen, having access to such information. In turn, this makes some assumptions about the nature of the society in which the citizen lives. That is, it is hard to argue that a citizen, having received an appropriate science education and being scientifically literate, remaining scientifically literate in a society where citizens are denied access to the information they need to make informed decisions, and the political freedom to
do so. This is essentially the argument made by both the philosophers Karl Popper, in *The Open Society and Its Enemies* (1945), and Paul Feyerabend, in *Science in a Free Society* (1978, 1982). Although their characterisations of science differ in significant respects, they do make somewhat similar claims about the interrelationship between the individual, science and society: that the freedom to think in certain ways in a society entails characteristics of the society, not just of a scientific community in isolation.
3.6 The relationship between science and technology

The sixth and final example of a debate concerning the nature of school science is the relationship between science and technology. The term science and technology is found commonly in both specialist literature and in general use, such as the mass media. We have seen, for example, that the AAAS Project 2061 Benchmarks for Science Literacy discusses the natures of science, technology and mathematics in combination in its characterisation of science literacy. Similarly, we have also noted that the New South Wales primary (grades K-6) curriculum comprises six Key Learning Areas, one of which is Science and Technology, presented in a single syllabus. (We should also note that science and technology are separate in the NSW secondary curriculum, and in the Australian National Curriculum Framework.) Thus, while science is presented as a separate component or subject in most curricula, it is combined with technology in various contexts, leading to the question of how its relationship to technology could or should be characterised in the curriculum, considering the present thesis.

The ways in which the curriculum characterises the relationship between science and technology is ultimately a function of the education system that sets the curriculum. We noted early in the present thesis that there is no necessary connection between what various parts of society, including the scientific community, regard as science and the characterisation of this science in a school subject called Science: this connection is, at bottom, made by the decisions of education systems. This applies also to the relationship between science and technology in the curriculum: the relationship between the two will be characterised according to the decisions of curriculum developers and the education system. Thus in the NSW context, science and technology are combined explicitly in the Science and Technology K-6 syllabus; a notion of technology as at least applied science is implicit in the Science 7-10 and the senior secondary General Science and Science for Life syllabuses; and technology is given scant treatment in the senior secondary discipline-based courses of Physics, Chemistry, Biology and Geology. Other syllabuses in the NSW secondary curriculum specifically address various aspects of technology. Just as the school
subject Science should be grounded clearly in the scientific and metascientific literature if it claims to represent the broader entity in society known as science, subjects purporting to be about technology should be grounded in the technological and metatechnological literature. Further, the relationships between science and technology in the curriculum should reflect their characterisations in the literature.

3.6.1 Characterising technology

We turn, then, to characterisations of technology, both alone and with science, in the literature. The literature on technology is not as large as that on science, but there is sufficient for the purposes of the present thesis. We will take several approaches to reviewing the characterisation of technology in the literature.

Characterisations from the metatechnology literature

First is the characterisation of technology given in summary statements of technology in the literature; that is, the same strategy as the present thesis used for the analysis of science summary statements. See Appendix C. Clearly, an analysis as detailed as for the science statements is beyond the scope of the present paper. However, a preliminary analysis of a smaller set of statements indicates that the same dimensions of characterisation hold for technology as for science: knowledges, activities, purposes, structures, contexts and belief systems, although the semantic content of these dimensions is often different from those of science. That is, when applied to summary statements of technology, the same six semantic categories account for all textual units in those statements as also account for the text units in the summary statements of science. Thus technology can be characterised in similar dimensions, even though the content of those dimensions will differ from science:

- knowledges, both knowledge-how and knowledge-that, including tacit knowledge;
- activities, most notably craft activities through history, but also a range of other activities such as designing, making, organising and so forth;
- purposes, chiefly to deploy resources to meet human needs or wants;
structures, in several senses such as technological products, organisations, systems, and technological language;

- contexts, which lead to particular technological needs, resources and capabilities; and

- belief systems, that include the assumptions, beliefs, criteria for judgements and attitudes that enable particular technological activities.

The summary statements of technology in Figure C.1, like those of science, show a variety of characterisations of technology, but all can be represented using the same six dimensions of characterisation. It is interesting that entries from general dictionaries tend to characterise technology largely in terms of scientific application, and even simply as applied science, whereas statements from the metascientific literature include much broader views of technology. We will pursue these interpretations here.

**Characterisations from the metascientific literature**

The second approach is the characterisation of technology from a scientific perspective. We have noted earlier in this thesis the debates about pure, or basic, and applied science. That is, some commentators mark the boundary between science and non-science around the so-called pure sciences, as disinterested research for its own sake. This leaves applied sciences, with their complicating characteristics like economic and political purposes, as more to do with technology. Some, but not all, with this view characterise technology as applied science, but in any case see science and technology as quite different, based upon an essentialist notion of science and non-science. Other commentators either mark a different boundary or reject any such boundary: they either accept applied sciences as sciences, or dismiss distinctions between pure and applied sciences as meaningless or useless. These views also tend to characterise science and technology as being different, but as less clearly so. They emphasise the idealised nature of pure science, that in practice scientific research serves some end or other, and either becomes, seamlessly, part of a technological process, or is explicitly a part from the outset. When discussed within a scientific perspective, the technology tends to be analysed in terms of its relationship to science, but when discussed from other perspectives such as political, social or economic
ones, other elements of technology are also brought into focus that do not arise from
science.

Characterisations from other literatures

Thirdly is the characterisation of technology from perspectives other than technology
or science. We have noted in discussing the history of science that a criterion in discerning
the earliest human civilisations is the identification of technological artefacts, such as tools,
weapons and symbols for communicating ideas. This argument is that the artefacts
represent early technologies, and, perhaps secondarily, indicate experiential, trial-and-error
knowledge by which we later characterised science. For example, Zilsel (1942) has argued
that the emergence of classical science in the Scientific Revolution came about through the
union of three existing traditions, one of which was the craft tradition of technology or
know-how held by artisans:

Edgar Zilsel’s (1891-1944) theory related the emergence of modern science to
social change in early modern Europe. His central thesis identified three separate
intellectual strata in late mediaeval Europe: university scholars, secular humanists,
and artisans. The first two groups were the carriers of formally-systematised
rational, logical and mathematical modes of thought; the artisans were the
repository of experimental and observational techniques and causal thinking.
However, in the pre-capitalist social structure an unbridgeable gulf separated
practitioners of the ‘liberal’ and ‘mechanical’ arts. Systematic contact between all
intellectual strata was prevented by their distinct institutional and class locations
and by the prejudice entertained toward manual labour by social elites. With the
progress of mechanical technology and the social reordering brought about by
capitalism, Zilsel argued, the social barriers separating carriers of rational modes
of thought from carriers of causal and experimental thinking were lowered. The
city, as a politically free centre of capitalist production, provided a congenial
atmosphere for this development. ‘Superior artisans’ came to require the rational,
mathematical resources of university scholars and the secular learning of the
humanists, even as the scholars’ contempt for technique was overcome by new
socio-economic realities. By c1600 this merger of traditions was evident in the
work of Bacon (1561-1626), Galileo (1564), and Gilbert (1544-1603). In Zilsel’s
view, the general characteristics of a scientific cosmology were produced through
the hybridisation of conceptual resources which is in turn ultimately attributable to
capitalist socio-economic change. (Shapin 1983b, p. 450)

Thus the history of technology is not equivalent to the history of science.

Indeed, as discussed in Appendix B.1 on context, the predecessors of what is now
considered to be science are more accurately characterised as the concurrent traditions of
craft and natural philosophy before the sixteenth century in Europe. Zilsel’s thesis is that
the traditions of craft (technology) and natural philosophy were quite distinct, at least until the sixteenth century.

Partly consistent with this argument is Toffler’s thesis, in *The Third Wave* (1981), that characterises the history of technology by three distinct waves or stages\(^\text{15}\), none of which derives from a necessary foundation in science. Toffler’s three stages in technological history are, in historical order, the Agricultural Revolution, the Industrial Revolution, and what is often called the Information Revolution. The Information Revolution is an emerging wave of increasingly responsive, rapidly developing, diversified technology that has fundamental and diverse influences on, and from, all elements of society:

For the purposes of this book we shall consider the First Wave era to have begun sometime around 8000 BC and to have dominated the earth unchallenged until sometime around AD 1650-1750. From this moment on, the First Wave lost momentum as the Second Wave picked up steam. Industrial civilisation, the product of the Second Wave, then dominated the planet in its turn until it, too, crested. This latest historical turning point arrived in the United States during the decade beginning about 1955 - the decade that saw white-collar and service workers outnumber blue-collar workers for the first time. This was the same decade that saw the widespread introduction of the computer, commercial jet travel, the birth control pill, and many other high-impact innovations. It was precisely during this decade that the Third Wave began to gather its force in the United States. Since then it has arrived - at slightly different dates - in most of the other industrial nations, including Britain, France, Sweden, Germany, the Soviet Union, and Japan. Today all the high-technology nations are reeling from the collision between the Third Wave and the obsolete, encrusted economies and institutions of the Second.

Understanding this is the secret to make sense of much of the political and social conflict we see around us. (Toffler 1981, p. 28)

The point is that significant issues arise from the nature and history of technology that do not necessarily arise from the perspective of the history and nature of science. Toffler, for example, is keenly interested in the social implications of technologies, and the technological implications for society. As another example, the technological achievements of non-western European cultures such as China, discussed in the companion chapter on context and Appendix B.1, are much more straightforward than debates about the boundaries of science and non-science: we can readily identify histories of technological

\(^{15}\) Toffler elsewhere acknowledges that he could have constructed any number of historical stages, depending on the focus and level of analysis, just as the present thesis acknowledges its suggested six categories or dimensions of characterisation could vary according to the focus and purpose of the analysis.
achievements regardless of questions of natural philosophy, such their theoretical frameworks or underlying belief systems.

This discussion on the nature of technology, then, calls for a broader interpretation of technology that acknowledges its frequent links with science without restricting technology merely to applied science. From the perspective of the present thesis, and in particular the present section, it is the relationships between science and technology that need to be clarified in the school Science curriculum:

Many modern technological developments are rooted in or closely connected with scientific developments. What can be said about the nature of this relation?

First, one should recognise that there are no sharp definitions of the concepts of science and technology. Often the two concepts have been reified into two 'things' that can have a mutual relation. Science, then, is understood as the body of knowledge widely accepted by the scientific community, which can be found mainly in scientific journals and books. Technology in its turn is understood to encompass both hardware and knowledge of the industrial arts (E. Layton 1977). One way of relating science and technology, then, might be to look for the similarities and differences between the two types of knowledge, for example, as to their nature and structure. A different way would be to ask how scientific knowledge is transformed into technology. The first is a static relationship; the latter, a dynamic one, which actually refers to the activities of scientists and technologists. (Smit 1995, p. 616)

This is not to argue that the science curriculum should also deal extensively with the nature of technology; that could, and probably should, be dealt with in technology subjects. However, the science curriculum should show how science is characterised commonly in conjunction with technology, as discussed in the companion chapter on context and Appendix B.1:

[S]cience stands in a special relationship to industry, which is itself a source - perhaps the major source - of negotiating power in the modern state. The third section [of our article] attempts to situate the actions of science elites, their allies, and their potential or actual adversaries within the structural setting of market-oriented societies [which are broadly similar across technological societies with very different polities and economies]. When governments leave the development and distribution of technologies to private corporations, publicly funded research serves primarily as an inducement to the private sector to perform this function, and only secondarily as a form of public choice of knowledge or technology. Given the current structure of influence around science, research is much more likely to be pulled in directions chosen by industry than to be pushed toward democratically chosen ends, no matter how open the priority-setting process in government becomes. Thus democratic control of science depends ultimately on democratic control of technology. (Cozzens & Woodhouse 1995, p. 535)

Many school curricula, including the NSW curriculum, already deal with, or have the capacity to deal with, these issues, often disparately as science, design and technology, and
social studies. The argument of the present thesis is that a multidimensional school Science has the potential to make these elements explicit in ways that traditional science curricula do not. Confining the science curriculum to a predominantly internalist characterisation of science neglects one of the very characteristics of science that shows how science is used and influenced by society and technology, and equally influences them. A traditional assumption of science curricula is that students, having grasped a range of scientific concepts, understandings, propositions and inquiry skills, will then be able to apply these competencies in real contexts\(^{16}\). The present thesis has argued that internalist characterisations of science do not make these applications clear, and indeed, often reject these applications as being beyond the realm of particular science communities. It has also argued that metascientific analyses in the last decades of the twentieth century have largely rejected strictly internalist characterisations of science, many of them arguing that we need to understand, among other things, the social and technological applications of science and influences on it. It suggests that the links between science and technology can be made by making clear their shared contexts, purposes, and so forth. Because the school Science curriculum provides both the preparation for future scientists and technologists, and the last formal science education for many others, it has to make clear the nature of science in relation to technology and society in general. In the same way, it has to make clear the nature of technology and of society, but that issue is beyond the scope of the present thesis.

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\(^{16}\) This is commonly traced to Robert Gagne’s notion of hierarchical learning, but also has direct roots in science education to nineteenth century theorists (DeBoer 1991).
4. The present thesis has implications for the selection of curriculum models and resources, teacher training and school organisation.

Finally, we now turn, in sections 4 and 5, to a more speculative mode, to suggest some wider implications and areas for further research arising from the present thesis. Section 4 presents some issues that arise for the science curriculum generally, although they could apply also to the broader curriculum. Section 5 speculates on some implications of the present thesis for theorising about the curriculum generally. Specifically, it explores the question of whether and how the present thesis could apply not just to science but other subjects and the curriculum as a whole.

We have discussed at length the implications of the present thesis for deciding which curriculum models will best accommodate a robust characterisation of science: that is, which will provide for adequately characterising science. However, it also has implications for making decisions about curriculum materials, teacher training and school organisation.

4.1 Implications of the present thesis for selecting curriculum models

The present thesis argues that decisions about curriculum models should present a multidimensional characterisation of science that is grounded clearly in the literature. This section will make some recommendations that apply both within the present, narrow, constraints of curriculum development practice, and within broader contexts. Section 1 of the present chapter reviewed a variety of curriculum models that arise from a variety of curriculum goals, such as those arising from various curriculum policies, ideologies and organisations. Many of these goals are plausible to many curriculum stakeholders, and the multiple goals of curricula reflect the multiple purposes of the curriculum and the pluralistic nature of curriculum stakeholders. Further, a single goal can arise from more than one perspective. For example, the goal of gaining knowledge can be justified by one or more of: policy goals, including the goals of worthwhile knowledge, the curriculum as a rational system and the curriculum as control; ideological goals, including the goals of religious orthodoxy, rational humanism, progressivism, critical theory, reconceptualism and
cognitive pluralism; and organisational and structural goals, including disciplinary structures, structures based on the characteristics of learners, and structures based on social issues. In this example, each of these goal clusters requires the gaining of knowledge, although the nature of that knowledge is characterised variously.

Given the purpose of the present thesis, and particularly the discussion in the present chapter, we will make the assumption that education systems will continue to offer a subject, *Science*, in the school curriculum, because they will continue to structure the curriculum around worthwhile knowledge based on the established disciplines. This assumption rests on the following prior assumptions. First, the present thesis addresses the mainstream curriculum in pluralistic democracies such as Australia, New Zealand, the UK, western Europe and the US. Therefore, it does not place a great emphasis on curriculum models, such as reconceptualism, progressivism and (at higher grades) child-centred curricula, whose main support is from curriculum academics and not the spread of curriculum stakeholders. While the present thesis acknowledges some of the insights and potential benefits from those goals, which may indeed be included in actual curricula, it sets a higher priority on making recommendations that have a higher chance of implementation in the education systems it addresses. Secondly, the present thesis makes no claim that there necessarily has to be a distinct school subject called *Science*, because a multidimensional characterisation could be presented both within a subject called Science or within some other curriculum structure. However, considering the earlier comments, it seems probable that the targeted education systems would be unlikely to delete from the curriculum a subject called *Science*, even though its content may still be covered in a reconceptualised curriculum.

As a general statement, therefore, the present thesis evaluates the various curriculum models according to how they allow for, or encourage, a multidimensional characterisation of science. Thus the tendency towards increasing government presence in curriculum policy, as noted by Elmore and Sykes (1992), means that arguments about the nature of school Science needs to be made partly at the political level; clearly, it is not enough to restrict the argument to the domain of direct involvement in curriculum development. In
turn, this means that the argument has to be made in the mass media to inform public opinion. It is significant, as noted earlier, that perhaps the dominant strand of science education research since about the mid-1980s has been constructivism and the notion of children's science, yet this is barely identifiable in curriculum policies during that time\textsuperscript{17}. Instead, the predominant educational themes in political policies across the political spectrum in most western countries during this time has been increased efficiency, and so-called ‘declining standards’, as reflected in concerns with improving behaviour and educational ‘basics’ - literacy and numeracy. Following from this, the enduring goal of worthwhile knowledge has persisted, even strengthened, but with a shift towards traditional notions of knowledge-that and narrow conceptions of knowledge as disciplines. This is reinforced by increasing concerns with curriculum efficiency and examples of the curriculum as a rational system, as a means of control, and curriculum as capital. Together with shifts in goals at the level of government policy, from equity to diversity and choice, these changes have supported curriculum models based around traditional subjects. This has meant that even relatively recent additions to the curriculum, like technology, have been introduced as new subjects, such as Design and Technology and Computing Studies in NSW. In turn, this model has yet to address tensions in the total curriculum: the sense that technology is a ‘seamless web’, applying across all subjects, is difficult to reconcile with the discrete subjects that typically comprise secondary curricula. Attempts to implementation technology as a cross-curriculum perspective are yet to be shown to be successful.

\textit{Some design implications of a multidimensional characterisation}

The central question here is, what acceptable curriculum models entail, or at least accommodate, a robust, multidimensional characterisation of science? An early decision has to be whether a multidimensional characterisation is presented as a single subject, or

\textsuperscript{17} The New Zealand science curriculum is a notable exception. Matthews (1995) is highly critical of it because it is structured around a disputed (constructivist) characterisation of science. The present thesis is also critical, but more because the opportunity created for establishing a multidimensional approach, by rejecting the traditional positivist paradigm, was lost, and also because the replacement was largely another single paradigm.
whether different dimensions are emphasised in different subjects: the former would require changes in teacher training and resource development and allocation, and the latter would capitalise on existing expertise and resources.

An example of such a decision is in the preliminary development of the NSW *Science and Technology K-6 syllabus* (1990), with which the present author was involved. At the beginning of its development, there existed the 1980 *Investigating Science K-6 Policy* (syllabus), whose stakeholders expected to see it retained in any new syllabus, but there was no technology syllabus and indeed no comprehensive, formal notion of technology in the curriculum. Developmental work in computer education, mass media education and craft and design education already existed, and each of these stakeholder groups expected to see a new syllabus developed in 'their' area. Thus an early question to be answered was how were science and technology to be fitted into a developing curriculum with fewer syllabuses? One view put was to treat *science, technology and society* essentially as separate: *Science* would cover natural science, mainly nature study; *Technology* would cover the so-called *technological sciences*, like electronics and computing; *Craft and Design* would cover mass media education, designing and making; and *Social Studies* would cover the social implications of science and technology. This view was rejected in favour of treating science and technology holistically and in contexts that are meaningful to students. In particular, to split technology artificially would leave the overall curriculum with no comprehensive presentation of technology to guide teachers.

To return to the present thesis, the same issue confronts school Science, as in the difference between its traditional character and the multidimensional character argued here. One could argue that the subject Science should remain essentially internalist and acontextual, and interactions between science, technology and society could be done in the social sciences and perhaps studies of technology. However, the present thesis argues that, while the social sciences provide the scope to treat the societal implications of science and technology, and some new technology subjects have a broader scope than the narrowly technocratic nature of traditional technology subjects, a robust, multidimensional understanding of science is unlikely to form unless this characterisation is presented in a
planned and cohesive course of study. Therefore, given the subject-based nature of traditional, mainstream curriculum models, this goal is most likely to be achieved in a single, multiple-stage subject, *Science*. Further sociological, mathematical, linguistic, historical, technological and other implications can be linked to other subjects in the curriculum, and perhaps even to new, dedicated elective subjects devised expressly to pursue such issues as extensions. However, an overall, robust characterisation is most likely when a subject is devoted to that purpose, regardless of what additional courses may become available as extensions.

*Some broad, content implications of a multidimensional characterisation*

The next question is, what should be the nature of such a subject? Given the analysis in the present thesis, it should not comprise an extreme internalist or externalist view of science. Students will need to develop understandings of current scientific knowledge, as well as some (metascientific) understandings about science. We have seen earlier in the present thesis that traditional school Science knowledge tends at the same time to be not current enough and acontextual; it does not provide insights from historical, sociological and philosophical perspectives. Thus careful thought will need to be given to provide a balance between:

- the enduring concepts, beliefs, activities, purposes, contexts and structures, many of which comprise most of traditional science curricula;
- recent examples and likely or possible developments, so that school Science remains up to date with the sciences and to give students an appreciation of the pace and scope of changes in science;
- science in historical, sociological and personal as well as intellectual contexts, so that students develop a more robust understanding of science, and see science as more relevant;
- different metascientific views, so that students gain a variety of insights into science - learning something about science, rather than simply science concepts - and that different individuals and groups characterise science differently and for different reasons; and
• the different dimensions of characterisation.

On this last point, it is not intended that the six dimensions of characterisation presented in the present thesis somehow be given equal time in the curriculum, nor that they be accepted as immutable categories. Much time will still need to be spent dealing with accepted scientific concepts and understandings, but students should develop an appreciation that these understandings arise from, and in conjunction with, characteristic activities, purposes, structures, contexts and belief systems. Further, the dimensions are not presented as absolute or immutable, but as constructed from this analysis of statements about science that built on the common and enduring dimensions of knowledge and process.

These goals require sufficient time to address prior understandings and beliefs, and to develop the broader framework of understandings and skills they entail. This is consistent with long-term criticisms of the science curriculum that fewer topics should be covered, but in greater depth, to foster knowledge as personal understanding rather than low-order intellectual activities. Some of the more obvious strategies would be to include, or increase, the use of case studies and extended investigations of current, historic and projected examples of science, and the science involved in social and personal issues. These should be selected so that, over the course of some years, students gain an understanding of the multidimensional character of science, and an ability to apply this understanding to appraise social and personal issues, claims to reliable or authoritative knowledge, and so forth.

This approach to science education should be made clear at every level of curriculum policy and curriculum statement, from statements of the rationale for and general nature of the science curriculum, to individual syllabus documents.

4.2 Implications of the present thesis for teacher training

The education literature is clear that the central factor in the success or otherwise of any curriculum is the teacher. In Australian and similar education systems, the most commonly required qualification for science teachers is a degree in science together with additional training in education. This has been the traditional means of teachers learning
something of the complexity and scope of science knowledge and gaining some competence in laboratory and investigative skills. However, it provides limited preparation for teaching about science. The teachers of multidimensional science will still need to have a robust education in science, that is, tertiary studies in science. However, it seems probable that much of the metascientific expertise among teachers, at least in Australia, lies not just with science teachers but also with teachers of the social sciences, technology, history, linguistics, and so forth. For example, English teachers with knowledge of linguistics, such as functional grammar, have detailed knowledge of scientific language structures and genres; and many historians and social scientists have sound knowledge of historical and social contexts of science.

Clearly, some of the teaching force will need to have expertise in education about science, and there are several possible strategies for addressing this. One possibility is to leave the subject Science essentially as it is, dealing mainly with internalist understandings of science concepts, propositional knowledge and experimental skills. Other characteristics of science could then be dealt with by teachers with other expertise, as mentioned in the paragraph above, either within the subject Science, or within their own subjects. This view has some attractions, such as encouraging links across the curriculum that exist already to a limited extent, and using existing expertise and patterns of teacher training. These strengths should be kept in mind as we examine the implications for the subject Science.

The present thesis has argued that school Science should be a robust education in and about science. This means not just extending the traditional scope of school Science, but treating science more comprehensively so that the interplay of its multiple dimensions can be understood. School Science, therefore, should be taught as a cohesive and meaningful entity. This means that the presentation of scientific understandings, for example, should not be separated from the characteristic activities, purposes, structures, contexts and belief systems that lead to this knowledge and give an understanding of its character. Similarly, one could not meaningfully address the social impact and utility of science, for example, or the characteristics of science language, in isolation of the theories, activities, purposes, assumptions and criteria used by scientists and others in claiming this knowledge. It would
certainly help to have other school subjects to deal with these characteristics also, or to have other non-science teachers contributing their expertise in science. However, regardless of these strategies, the teaching of science knowledge and experimental skills should not be taught independently of other characteristics, including the broader notions of science knowledge and activity. That is, those responsible for teaching science will need to have a broader understanding of science and about science than has been required traditionally. If they also teach science with other curriculum specialists, either within the subject science or in other subjects, that is all to the better, but there must be somewhere in the curriculum for a robust and comprehensive treatment of science.

4.2.1 Implications for the pre-service training of teachers

The implication for pre-service teacher education is that tertiary studies should not only be in science, in the sense of studies of physics or biology, for example, but also about science, in the sense of science history, philosophy, sociology, policy, perhaps in combination. Similarly, studies in science pedagogy and programming should ensure that beginning teachers are able to implement a robust characterisation with appropriate and effective teaching and programming strategies. Thus, while the majority of Australian science teachers complete an initial science degree, that degree should include some metascientific study, such as in HPS and STS. This is not universally available in Australian universities, but teacher employing authorities already set requirements for patterns of study that teacher training institutions must furnish if their graduates are to be employable; it is not a difficult issue in the medium to long term.

4.2.2 Implications for the in-service training of teachers

There are also implications for the in-service training of teachers. One is the task of complementing the knowledge, skills and attitudes of existing science teachers: a robust, multidimensional characterisation of science is outside the experience of many science teachers, and certainly outside the expertise of a good many more. Thus teachers will need

18 Notwithstanding that teachers' studies in metascience do not guarantee improved student learning (Gaskell 1992).
to have opportunities to develop metascientific understandings - understandings about science, as well as scientific understandings of the material world. This should include at least some introductory work in the history, philosophy and sociology of science, to develop an understanding of the multidimensional character of science, and some familiarisation with curriculum and teaching support materials.

Another is the ongoing maintenance of the currency of teacher expertise. This recognises that traditional science curricula have emphasised the received knowledge and laboratory skills that are believed to be central to science, suitable preparatory work for higher understandings and skills, and enduring. Thus traditional science curricula are far more conservative than the present thesis advocates: while a syllabus may not be out of date in the sense that it is based on enduring concepts, it can be out of date in the sense that it may not include recently developed understandings and theories. Appendix B.6 on knowledge showed that one characteristic of science knowledge is the rapid increase of its volume and rate development. Likewise Appendix B.1 on context showed that another characteristic is the increasing involvement in developing and disputing science of groups outside 'pure' research, such as universities, industry, government and citizen groups. These characteristics should complement enduring and fundamental knowledge and skills. The conservative character of traditional school Science has meant that school Science programs and teaching changed very slowly\textsuperscript{19}. There is a need, therefore, for school Science to include recent, current and probable scientific developments, and to include recent, current and possible science issues requiring scientific literacy. In turn, education systems should provide for regular updating of teachers' expertise in and about science, either by encouragement or requirement, and either further formal post-graduate qualifications, or other 'update' courses provided by school systems in collaboration with universities and/or industries.

Non-teaching support staff, school executive staff, people with scientific and metascientific expertise, and others, act as resources for science teachers and would also

\textsuperscript{19} For example, an academic chemist on the NSW chemistry syllabus committee complained to the present author in 1988 that secondary school chemistry was basically the chemical knowledge that existed in the early 1900s!
need training. For example, non-teaching support staff, both within and without the school, provide logistical support for science education. This includes the laboratory assistants, who provide and maintain apparatus, chemical stocks, and so forth, and manage laboratories. Most laboratory assistants also have a role as teachers aids, managing the inventory of science texts, audio visual resources, and so forth. The school executive are also resources, in that they are necessary agents of change and implementation support: logistical support at the school executive level is necessary to enable schools to respond to curriculum changes. This is so particularly where teachers from more than one faculty implement a particular syllabus, but also for coordinating the scope and overlap of the school curriculum and the demands this places on timetabling, resource allocation and staffing. People with scientific and metascientific expertise are resources for curriculum development and implementation by education systems and schools, for teacher development and as primary sources for students and teachers. This group includes not only scientists, but could include metascientists, technologists, authors, and representatives of relevant interest groups, where their expertise is appropriate.

4.3 Implications of the present thesis for science education resources

There are implications for resourcing a multidimensional science curriculum model, meaning human, material and organisational resources.

Resources would need to be produced to the extent that this multidimensional view of science represents a change to existing curricula. A new curriculum would mean some expansion of teaching resources, but not a significant amount. The greatest expense would be the production and purchasing of resources like new texts, videos, kits and CD ROMs. We have noted earlier in the present thesis that texts are not as central to Australian curricula as in some other education systems, such as in the US. Regardless of the usage of any resources, there will be a need for resources to be produced to support new curriculum directions. We noted earlier that in some school systems, such as in some US systems, resource producers have a say in the development of curricula and that this has helped distort school Science. This thesis can only urge that those responsible for science
curriculum development be firm in their requirements for a multidimensional characterisation of science.

Organisational resources include the provision of curricula, curriculum implementation strategies and teaching staff by school systems, and the participation of teacher training institutions, teacher unions, groups of scientists and others with relevant expertise. The need identified by the present thesis for up-to-date expertise in scientific developments and social issues that involve science means that a more robust science curriculum is likely to create or expand the need of schools and teachers to draw more systematically on a wider variety of resources than previously. Having a syllabus that specifies up-to-date science places demands for teachers with up-to-date expertise. This would require more systematic support than the present ad hoc or absent arrangements. Planned networks, involving universities and science teacher associations, would be an effective solution.

4.4 Implications of the present thesis for school organisation

A multidimensional characterisation of science would lend itself well to more flexible approaches to school organisation. Examples include: theme- or issues-based approaches that integrate across two or more traditional subjects; a more flexible school organisation that allows for extended investigations, visits to pertinent sites and groups, and so forth; and more flexible staffing to capitalise on the combined expertise of teaching staff. However, none of these is a necessary condition. A multidimensional characterisation of science would provide greater pressure for changes of these types if other curriculum areas, like mathematics, technology and social studies, were also characterised in multiple dimensions, as explored in section (5) below. However, an express intention of the present thesis is to address the mainstream curriculum, and in that case we have speculated above that the most likely organisation of the school curriculum will continue to be the subject-based model that has been the most favoured model. The reason is simply because a change from this model is likely to lead to changes of school organisation, including staffing, timetabling and resource management, and other pressures such as industrial negotiation.
and fiscal planning, all of which contribute to pressures on schools to remain as far as possible the same as they are. A multidimensional school Science can be implemented within existing, subject-based curricula, and so issues of school organisation should be no barrier to its implementation.
5 The present thesis suggests several areas suitable for further research, and possible tests of its claims.

Finally, it is common in theses of this type to suggest areas for further research. This is not a euphemism for suggesting that a piece of research did not reach the conclusions it set out to reach\(^\text{20}\). To the contrary, it is claimed that the present thesis has indeed constructed a characterisation of science suited to theorising about curriculum development, as it set out to do. This result can then be:

- explored for its theoretical, practical, philosophical and other implications;
- developed in detail to suggest particular strategies for its implementation in particular contexts;
- extended in scope to other domains within the curriculum, and perhaps to the whole curriculum;
- applied, not only in curriculum issues, but perhaps to other, non-curriculum, fields such as policy or the public understanding of science;
- tested to see if its characterisation of science is sound and useful; and
- analysed for its contribution to methodology, curriculum, science policy and other issues.

Suggestions for further research are intended to show that the analysis has extended the field, and provides insights that support and stimulate further investigation. Accordingly, the present thesis suggests that there is scope for further research based on its analysis and theorising about the science curriculum.

5.1 The present thesis may apply to other subjects or domains within the curriculum, and to the curriculum generally.

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\(^{20}\) This was suggested by the late Professor Ron King to a post-graduate colloquium hosted by the Faculty of Education at the University of Wollongong; that he was dismayed that a number of theses sent to him for examination did not reach their intended goals for the likely reason they were poor examples of research. In some of those cases, the suggestions for further research should have been part of the original study and acted upon!
One emergent issue is whether the multidimensional characterisation proposed in the present thesis applies more widely to the curriculum than just Science. This suggests the hypothesis that the multiple dimensions used to characterise science in the present thesis may apply also to other subjects in the curriculum, and perhaps to the curriculum generally. That is, there is scope for further theorising that domains of the school curriculum, like discipline-based subjects or the Key Learning Areas in the NSW curriculum, can be characterised using these same six dimensions: knowledge, activity, purpose, structure, context and belief system. For example, we have seen in the summary statements of technology, given in Figure A.2, that the six dimensions constructed for science apply equally to technology. It is possible that alternative dimensions might have emerged had we started afresh from the metatechnological literature, but the dimensions constructed from the science statements accounted for the admittedly smaller sample of technology statements and text units. Further, informal discussions with a straw sample of historians and mathematicians secured agreement that, in principle, these dimensions apply also to their fields. Again, they reserved any final judgements because, given a chance to analyse their respective literatures, they may prefer other dimensions, but that the set constructed for science accounted for likely, comparable, statements in their fields. There are two choices for applying the approach of the present thesis to other fields: to construct a fresh set of dimensions from the relevant literature, or to apply the six suggested here to the other field. This choice in itself would be an avenue for further study.

A further hypothesis is that the curriculum as a whole is characterised in six dimensions: knowledges, activities, purposes, structures, contexts and belief systems. In this view, legitimate domains within the curriculum, like subjects, key learning areas or domains, are cohesive clusters of these characteristics. That is, the curriculum could be viewed as clusters of knowledges, activities, purposes, contexts, structures and belief systems. This is not to argue that the curriculum is another ‘subject’, rather that if it is analysed in the same way it may also be characterised as multidimensional, and have the same dimensions.
The argument is as follows. The six dimensions of characterisation are simply linguistic categories - categories of the way language has been used to characterise science. We have noted that examples of characterisations typically use several, and often all, dimensions in combination, where the dimensions act as an interactive set. That is, belief systems, purposes, knowledges, processes, structures and contexts do not act independently of each other. A decision about one or more entails decisions about at least some of the others. An analogy would be spilling out a box of children’s construction bricks on the floor. Let us say that these bricks are characterised, within the set, by their size, shape and colour. A decision to build something with them automatically clusters the possible decisions that can follow, meaning the possible uses of the remaining blocks. Choice of a red block automatically precludes the construction of an all-blue bridge. Choice of a large, flat block necessarily limits the possible shapes that we can end up with; in this case we can go on to build larger and stronger structures, but not small ones. Changing any of these decisions means that a new cluster of characteristics will form or emerge. Thus choosing a small block will allow structures that are smaller, but not as strong. Likewise in science, a different belief will lead to different assumptions that may lead to different purposes or activities; a different context may lead to different assumptions or structures; any of these changes may lead to different knowledge claims.

The same applies to school subjects, and indeed the curriculum as a whole: initial decisions about beliefs, or structures, or purposes, or concepts, for example, entails some later decisions and denies some others. Thus the present thesis could be used both to analyse existing curricula structures as clusters of these dimensions, and to construct new curriculum domains, using the dimensions argued here.

5.2 The multidimensional characterisation of science can serve as an analytical framework.

The multidimensional characterisation of science can serve as a framework for further curriculum theorising, and analysing claims about the nature of School science, pedagogy, curriculum policy, curriculum resources, ideology, and so forth. First, it may serve as a
stimulus to further theorising about characterising the nature of science in the school curriculum. In particular it may stimulate other attempts to characterise science for the school curriculum (or other purposes), with the possibility of suggesting that more or fewer dimensions, or perhaps a quite different set of dimensions, characterise science more meaningfully. Secondly, the characterisation attempted in the present thesis is significantly more robust than has been the trend in the science education and curriculum literatures. Therefore it provides a well-grounded theoretical framework to use in analysing science curricula, pedagogy, the understandings that students, teachers and others have of science, curriculum policy, resources, ideologies, and so forth. That is, explicit or implicit statements or assumptions in these literatures and public documents about the nature of science and school Science can be analysed by comparison with the metascientific meta-analysis given here.

5.3 The multidimensional characterisation of science can serve as a basis for curriculum and curriculum resource development

It should be remembered that the primary purpose of the present study was to provide a framework that would allow curriculum stakeholders to meet and contribute their respective insights. However, implicit in the present thesis is that this framework could also serve as a theoretical framework for the (science) curriculum itself, and not just as a meeting ground for stakeholders. To recall Schwab’s (1973) notion of subject matter as one of four curriculum commonplaces, the six dimensions proposed here could easily serve as curriculum commonplaces, just as knowledge and processes have served as organising themes in traditional science curricula. In studying scientific or science-based themes, students should gain an understanding of how these dimensions contribute to an overall understanding of science. The present thesis can therefore serve as a basis not just for further research, but also for development of curriculum and learning materials.

This multidimensional characterisation can thus be applied to texts and other curriculum support materials as an adjunct to existing mainstream curricula and curriculum resources. In this role it provides the criteria and conceptual resources for analysing or
developing curriculum materials, teacher knowledge, and so forth. One avenue of research is to devise, trial and evaluate such materials. Another is to evaluate existing curriculum materials in terms of the present analysis rather than just in terms of the curriculum in question. We have argued that this would represent a more demonstrable and higher standard of rigour.

5.4 Tests of the limits of this theory

Finally, in claiming to be a piece of scholarly theorising, and not empty speculation or dogma, the present thesis claims to have testable limits and the capacity for falsification in principle. Of course, a strong theme in the considerable discussion in Appendix B is that there is no single view of what constitutes a scientific, or other, theory! However, the present thesis set some limits as to the type and scope of its theorising, in particular to address the mainstream curriculum and its stakeholders. Here, in the conclusion, it claims to have met this goal: to have constructed a theory of the characterisation of science for use in the development of mainstream school curricula in at least western, pluralistic democracies.

First, it accommodates the diverse views given in the literature advocated by present and likely stakeholders, including metascientific views that conflict, a goal set in the introduction. This is because it was constructed from those very views. That is, it succeeds because:

- it does not reject contrary views of curriculum stakeholders;
- it provides a better fit than other models for the diverse views of stakeholders;
- it accommodates diverse but broadly accepted science and general curriculum goals; and
- it provides a better grounding in the scholarly literature than existing curriculum models and goals.

These claims could be tested by curriculum stakeholders reviewing the initial analysis and subsequent argument.
Secondly, its dimensions are suitable for the school Science curriculum, because they are:

- consistent with, and inclusive of, the widely used dimensions, knowledge and processes;
- discernible in examples of science appropriate to school students; moderate in number and therefore neither too numerous to remember and understand, nor so few as to be general and vague;
- constructed using a relatively straightforward semantic analysis that does not presuppose a particular philosophical stance; and
- clear and meaningful as dimensions of science.

We have noted that curriculum emphases, such as proposed by Roberts (1982), can be differentiated and applied at different stages of the school curriculum. Similarly, different elements within dimensions of science can be emphasised at different stages: some of the more complex notions of belief systems and context, for example, would not be addressed until middle or upper secondary years, as is done now for grading conceptual difficulty. This claim could be tested by analysing trials of multidimensional science curriculum materials and/or courses.

Thirdly, it makes no claim that its characterisation is in some way the true account, and indeed rejects the argument that there could be even a notion of any true view. It simply claims to represent meaningfully and economically a large amount of data, namely the variety of views of science in the metascientific literature. Among these findings was that, to the extent there is a consensus among current metascientific views, it is that there is no single, received view, and that notions such as truth are at least complex and in many views, contingent. This representation is offered to science curriculum stakeholders as a useful and meaningful tool for grounding school Science better in the literature.

Fourthly, the theory can be tested by looking for disconfirming instances, as follows.

(i) One type of disconfirming instance would be the advent of a metascientific argument that is accepted by science curriculum stakeholders but cannot be recast using the six proposed dimensions. The present thesis has applied its
multidimensional characterisation to show that it does apply to various metascientific views, and facilitates comparisons and critiques of them. There must always be the possibility that a future account will not fit, meaning that it cannot be recast meaningfully in terms of the six dimensions. However, the broad collection of views mentioned in the present thesis all fit; that is, the present thesis gives a useful account of existing views. While this is unsurprising, since the dimensions were constructed from the literature, inductively the multidimensional characterisation appears likely to account for future metascientific views within known paradigms. Disconfirmation in this sense would be made by appeal to semantic and metascientific arguments.

(ii) A second type of disconfirming instance is if the present thesis can be shown not to account for the data as it claims. Great pains were taken in the present thesis to represent robustly very substantial literatures, and to do so using methods of analysis that made clear their paths of reasoning. While individual stakeholders are not expected to agree with some or even many of the alternative views addressed in the present thesis, it is hoped that they will agree that their preferred view is adequately represented. However, argument that a particular view or particular data is misrepresented, would be grounds for arguing that the thesis is disconfirmed. Disconfirmation in this sense would be made by appeal to metascientific and methodological arguments.

(iii) A third type of disconfirming instance is if any alternative theory accounts for the same data more meaningfully, economically and/or more usefully. The sort of curriculum theorising advanced in the present thesis is only as meaningful as it is useful, or potentially useful. The present thesis has critiqued existing attempts to characterise science, and found them to be inadequate. The test of its usefulness in comparison with alternative accounts will depend on how school systems, academics and others respond to it, and these responses will depend in turn on many additional factors, including the ability of the present author (and others) to follow up this thesis with further ideas. This type of test is somewhat different to
the first two. Disconfirmation in this sense would be made not by appeal to semantic or metascientific arguments, but to educational and other arguments: that the thesis fails, or is found inferior, because it does not apply to the curriculum in the ways it claims. Given the complexities of curriculum development and implementation, this would be a difficult basis for disconfirmation: it would be hard to show that curriculum failure was due explicitly to the implementation of the present thesis. More likely, perhaps, is that a particular theory is blamed for ideological or other reasons. Nonetheless it is possible, in principle, to show the contribution of particular theories, such as given in the present thesis, to curriculum failures.
And in conclusion

It has proven a difficult task to provide a robust means of characterising science for the curriculum: the literature is immense; the diversity of views about both science and school Science is great; conflicting views are often fervently held; the balance between depth and breadth is inherently difficult to strike in a task such as this; and the state of science curriculum development is dynamic and difficult to encapsulate. For all these reasons the thesis has finished up much larger and more comprehensive than initially expected. However, there are two reasons that perhaps are more significant. One is that, as the writing and thinking progressed, I became increasingly aware of the multiple dimensions of science in text of many kinds, including media reports, textbooks, curriculum documents, advertisements, dramas, comedies, documentaries, cartoons: in other words, in the daily experiences of students and citizens. The other is that, whenever drafts of the thesis were presented to curriculum stakeholders from any constituency, its central task was taken very seriously and perceived omissions and biases were keenly contested. Time and again there seemed no solution other than to address explicitly each characteristic and each dimension of science. Moreover, these interactions confirmed and reconfirmed the decision to base the argument on the literature analysis, because no other source met the criteria of all concerned. These interactions also confirmed the importance of the task for science curriculum stakeholders, even though its primary audience will be restricted by its very thoroughness, and it contributes but one element of what will always be a process that is complex and never to everyone’s satisfaction.
VOLUME II

Appendix A: The Semantic Analysis and Construction of Categories

Appendix B: The Review of Metascientific Arguments and the Construction of Dimensions

Appendix C: Summary statements of technology

Bibliography

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APPENDIX A

A collection of summary statements of science from the literature

S.1  '(Science is)
1a. the systematic study of man [sic] and his environment based on the deductions and
    inferences which can be made, and the general laws which can be formulated, from
    reproducible observations and measurements of events and parameters within the universe;
1b. the knowledge so obtained;
2. systematised knowledge in general;
3. a particular branch of knowledge;
4. skill; proficiency.'
    The Macquarie Dictionary, 1985

S.2  'The task of science is to both extend the range of experience and to reduce it to order.'
    Neils Bohr, Nobel physicist, quoted in NSW Department of Education 1988

S.3  '(Science is) all exploratory activities of which the purpose is to come to a better understanding
    of the natural world.'
    Sir Peter Medawar, Nobel scientist, quoted in NSW Department of Education 1988

S.4  'Science is
- a developing body of knowledge - observations, concepts, laws and theories - which seeks
  to explain objectively the world around us
- a set of processes for observing, experimenting with, describing, classifying and analysing
  the phenomena of that world
- traditionally studied as a number of disciplines with fluid and overlapping boundaries.'
    NSW Council of Science Syllabus Committees, 1987

S.5  'The term “science” defines a domain of human knowledge and activity within which scientists
    seek the systematic organisation of knowledge about the composition and functioning of the
    universe. Scientists attempt to acquire and organise knowledge about the universe and its parts
    and to explain, through the formulation of laws and theories describing natural processes, the
    interaction and interrelationship of those parts. Among the characteristics that distinguish
    science from other fields of human endeavour are the goal of explaining, with ever increasing
    precision, the nature of the universe in terms of uniform natural processes and relationships, and
    the commitment to the testing of proposed explanations by means of empirical observation and
    experimentation.'
    National Academy of Sciences of USA, quoted in NSW Department of Education 1988

S.6  'Science is the belief in the ignorance of experts.'

S.7  'Science is built up with facts, as a house is with stones. But a collection of facts is no more
    science than a heap of stones is a house.'
    Henri Poincaré 1902, quoted by Tripp 1985, p.563

S.8  'Science is an activity characterised by the search for understanding - for a satisfying explanation
    of some aspect of reality, this understanding being codified in statements of high generality
    (laws and principles), these being accessible to experimental tests.'
    Goldstein 1978, quoted by McKenzie 1987, p.167

S.9  'Modern science is a search for understanding expressed in laws or principles of greatest
    generality and which are capable of experimental test.'
    McKenzie 1987, p.167

S.10  'Science is the attempt to make the chaotic diversity of our sense experience correspond to a
     logically uniform system of thought.'
    Einstein 1950 quoted by Tripp 1985, p.562
S.11 'The purpose of science as an activity is to form conceptual generalisations about the many particulars of empirical evidence.'
Mannoa 1980

S.12 'Science is a word which describes a way of knowing.'
*South Australian Science 8-10 Curriculum Guidelines, 'Science: A Way of Knowing' 1988, p. 1*

S.13 'Science is a human activity that has evolved as a way of looking at the physical and biological world and a way of ordering its many facets and checking the validity of this order.'
'Science: A Way of Knowing', p. 1

S.14 'The term “science” is usually assumed to have a very precise and well-defined meaning. But it can in fact be used in a variety of ways to indicate:
(a) a set of procedures for verifying or falsifying claims about the world, and our place in it, and thus is distinct from either tradition or authority; this set of procedures usually includes highly technical measures often requiring mastery of mathematics;
(b) a set of conclusions or a body of knowledge about the world which result from these procedures;
(c) an institution or set of organisational arrangements designed for educating and accrediting scientists, approving or discrediting scientific conclusions, and for protecting the interests of the scientific estate;
(d) a myth, that is, a systematic set of beliefs about the nature of reality, about the appropriate way to relate to reality and about 'the discipline of the self' (Foucault) necessary to achieve an appropriate relationship to reality;
(e) an ideology, that is, an organised way of thinking about reality which serves to maintain and perpetuate structures and patterns of social domination and subordination.'
Kenny 1988, p. 24

S.15 'Science is not just a collection of laws, a catalogue of facts, it is a creation of the human mind with its freely invented ideas and concepts. Physical theories try to form a picture of reality and to establish its connections with the wide world of sense impressions.'
Einstein and Infeld 1938

S.16 'Science is a world picture. It is not a technique; it is not a form of power; it is not even simply an accumulation of knowledge. But it is a highly integrated form of knowledge which makes a world view.'
Bronowski 1978, p. 39

S.17 'Science is simply common sense at its best - that is, rigidly accurate in observation, and merciless to fallacy in logic.'
*Thomas Huxley, quoted in New South Wales Department of Education, 1988*

S.18 'We may conceive "science" (here taken in the broader and older sense to signify any general understanding which can respond to challenge and questions) as a system essentially relating to the development of knowledge. Component parts of this system are: the producers (researchers), the process of research, the products, the interests for these products, the reporting sub-system, etc. This system forms itself part of a larger system: science in society. There are many ways of looking at science - at the knowledge-producing and knowledge-distributing industries.'
Radnitsky 1970, p. x

S.19 'We conceive "science" essentially as a knowledge producing and knowledge improving enterprise.'
Radnitsky 1970, p. 1

S.20 'Science is an activity which takes place in a particular sort of tradition. The tradition is essentially centred in a paradigm, or conceptual structure, which has a naturalistic metaphysics and an empirical epistemology. The goals and objectives of the tradition are twofold, namely, to predict and control phenomena revealed by the metaphysics and epistemology of the paradigm, and to explain and understand these same phenomena.'
Gale 1979
S.21 “The restrictive meanings of “science”, limiting the term to empirical, positive (nonnormative), operational, falsifiable propositions, or even to systematic study of natural (nonsocietal, noncultural) phenomena, are confined to Anglo-American parlance. In French, German, Italian, Russian, Japanese, and most other languages, the words for ‘science’ stand for systems of knowledge acquired by sustained study. If one wishes to refer to natural sciences, the word ‘science’ will not do; one has to use a qualifying adjective or compound noun. There is no difference in these languages between scientists and scholars; the French savant and the German Gelehrte or Wissenschaftler may be a natural scientist, social scientist, historian, archaeologist, philosopher, literary critic, or writer on jurisprudence or on any learned discipline. This is reflected in the organisation of the academies of sciences in many countries…” Machlup 1980

S.22 “Taking account of the characteristics of science specified in the most authoritative dictionaries, encyclopaedias, and philosophic treatises in languages other than English, I have formulated a definition of science that reflects the broadest international consensus: science is a body of coherent, systematic knowledge of any subject, formal or empirical, natural or cultural, arrived at by any method whatever, provided it (1) is based on hard, honest and serious study and research and reaches insights not available to laymen or superficial observers and (2) is designed for either intellectual or general-pragmatic purposes, but not for immediate practical application in a concrete case or situation.” Machlup 1980

S.23 “Science throughout [this book] is taken in a very broad sense and nowhere do I attempt to cramp it into a definition. Indeed, science has so changed its nature over the whole range of human history that no definition could be made to fit … Science, in one aspect, is ordered technique; in another, it is rationalised mythology.” Bernal 1969, p.3

S.24 “Since a definition is intrinsically impossible, the only way of conveying what is being discussed … as science will be an extensive and unfolding description … Here …[are] the major aspects in which science appears in the contemporary world. Science may be taken, (1.1) as an institution; (1.2) as a method; (1.3) as a cumulative tradition of knowledge; (1.4) as a major factor in the maintenance and development of production; and (1.5) as one of the most powerful influences moulding beliefs and attitudes to the universe and man [sic]. In (1.6) the interactions of science and society are discussed. By listing these different aspects of science I do not intend to imply that there are as many different “sciences”. With any concept so wide-ranging in time, connexion and category, multiplicity of aspect and reference must be the rule. The word science or scientific has a number of different meanings according to the context in which it is used.” J.D. Bernal 1969, p. 31

S.25 “[There has arisen] a standard view [of science], largely shared by reflective scientists, technical philosophers, and the educated public alike, and laying great emphasis upon the objective features of scientific thought … For the standard view has not only been widely entrenched and long taken for granted; it has also … enjoyed the staunch support of the dominant scientifically oriented philosophies of our day. The current attacks thus challenge not only a firm set of habitual attitudes, but … the underlying moral motivation of these philosophies, their upholding of the ideal of responsibility in the sphere of belief as against wilfulness, authoritarianism, and inertia.” Scheffler 1967, pp. 7-8

S.26 “The reality thus revealed under the methodological publicity of scientific method is, moreover, a reality in which we are ourselves but limited natural elements. Our wishes and perceptions have not made this reality, but have sprung up within it as functions of organic development in a small corner of the universe of nature. Objectivity is not only, as we have seen, a fundamental feature of scientific method; the ontological vision in which it culminates is the vision of a universe of objects with independent existences and careers, within which scientific inquiry represents but one region of connected happening and striving. In short, for the standard view I have been describing, objectivity is the end, as well as the beginning, of wisdom.” Scheffler 1967, pp. 11-12
Appendix A: Figure A.1

S.27  ‘[The standard] view [of science] affirms the objectivity of science; more specifically, it understands science to be a systematic public enterprise, controlled by logic and empirical fact, whose purpose it is to formulate the truth about the natural world. The truth primarily sought is general, expressed in laws of nature, which tell us what is always and everywhere the case. Observation, however, supplies the particular empirical facts, the hard phenomenal data which our lawlike hypotheses strive to encompass, and for which it is the ultimate purpose of such hypotheses to account.’
Scheffler 1967, p.8

S.28  ‘The ultimate aim of science in the standard view is to discover truths about the external world.’
Riggs 1992, p.10

S.29  ‘What science gives us is criteria of judgement, methods and techniques for evaluating data, and a commitment to logic and rationality. All human knowledge is value-oriented because it is selective. What is relevant to a scientific problem and what has meaning in science depends on what we are looking for and what we are trying to accomplish.’
Gräfenfeld 1973, p.196

S.30  ‘Science is a deceptively inclusive word which refers to a variety of distinct though interrelated items. It is commonly used to denote (1) a set of characteristic methods by means of which knowledge is certified; (2) a stock of accumulated knowledge stemming from the application of these methods; (3) a set of cultural values and mores governing the activities termed scientific: or (4) any combination of the foregoing.’
Merton 1973, p.268

S.31  ‘...the value posture hospitable to scientific endeavour is rationalistic in the choice of alternatives, relativistic in judgement and expectation, and anticipatory of change. A pragmatic rationalism may be contrasted with a ritualistic motivation for action. A relativistic stance may be differentiated from an organic one; the relativist presumes that the effect of his actions will be something less than absolute, and thus he does not call into play every moral, ethical or religious precept to which he may subscribe on the occasion of his every judgement and action. In short, he can bring differing value judgements into play in accord with specific roles ... The values of science, to become effective, must be supported by more general societal values, as well as the public power, institutional structures, and class systems appropriate for the purpose.’
Silvert 1969, p. 231

S.32  ‘Science ... is common knowledge extended and refined. Its validity is of the same order as that of ordinary perception, memory, and understanding. Its test is found, like theirs, in actual intuition, which sometimes consists in perception and sometimes in intent. The flight of science is merely longer from perception to perception, and its deduction more accurate of meaning from meaning and purpose from purpose ...’
Santayana 1962, p.148

S.33  ‘Science is (and has been) considered by most of its investigators to be a community of individuals engaged in similar and related activities of inquiry ... Insofar as science is itself a community of inquirers, then it must necessarily have a philosophy, just like any other group of people asking questions ... I am not claiming here, in my notion of a “community”, that there are not disagreements ... but I want to emphasise to you that these disagreements are philosophical conflicts - conflicts, among other things, in regard to ultimate kinds of explanatory ideas ...’
Gale 1979, p.8

S.34  ‘Science is often conceived as a body of knowledge. Reflection, however, will lead to the conclusion that this cannot be its true nature. History has repeatedly shown that a body of scientific knowledge that ceases to develop soon ceases to be science at all. The science of one age has often become the nonsense of the next ... Science, then, is no static body of knowledge but rather an active process that can be followed through the ages. The sheer validity and success of the process in our own age has given rise to a good deal of misunderstanding of its nature and not a little misapplication of such terms as “science” and “scientific” ... [The terms] science and scientific as employed in these [popular] connexions have no relation to the great progressive acquisition of knowledge [called science].’
Singer 1959, pp. 1-2
Thus, what I need to do now is to describe for you an element of scientific activity, namely, its goals, which set it apart from other human activities.

The goals of science are twofold. The first goal is prediction and control. The second is explanation and understanding ... the two goals are not absolutes of all sciences. Some sciences exist today which apparently aim for only one of the two objectives. Behaviourist psychologists ... usually ... seek only to discover correlations between behaviours, which will be used solely for prediction and control ... On the other hand, some sciences are almost purely explanatory ... [such as] evolutionary theory [which] can describe the course of biological changes in the past, but ... cannot be much used to make predictions about the future ...

... One way to distinguish the prediction-and-control aspect of science from the explanation-and-understanding aspect is this: Prediction and control involve statements which use only correlations, whereas explanation and understanding involve statements which use causal connections.'

Gale 1979, pp. 61-62

While there is far from a consensus of beliefs in [the "new philosophy of science"], most of the following contentions would be affirmed by those working in it:

- that science is an open-ended, on-going activity, whose character has changed significantly during its history
- that science is not a monolithic enterprise
- that good science can lead to false theories
- that science has its roots in everyday circumstances, needs, methods, concepts, etc. of human beings
- that through examination of science we will learn how to understand such notions as "observation", "theory", "meaning", "reference", "explanation", "progress" and "rationality"
- that the boundary between a "scientific" question and a "philosophical" question, especially as regards foundational problems, is often blurry
- that the function of the philosophy of science is descriptive, critical, and normative
- that the philosophy of science is not self-sufficient, insofar as the methods of philosophy need to be supplemented by concepts, principles, theories, etc., drawn from other disciplines; though it remains to be determined just what can be used and how.'

Neressian 1987, p. vii

Our word "science" comes from a Latin word for knowledge. Much that we know does not count as science, but this is often less due to its subject matter than to its arrangement For nearly any body of knowledge that is sufficiently organised to exhibit appropriate evidential relationships among its constituent claims has at least some call to be seen as scientific. What makes for science is system, whatever the subject And what makes for system is the judicious application of logic. Science is then a fruit of rational investigation.'

Quine & Ullian 1978

'[Science is or involves] the methods by which we acquire knowledge of nature, and ... set that knowledge within a more comprehensive metaphysics.'

Harré 1986, Preface

'Actual science is a very complex activity, so it is not surprising that there have been several theories, expressing different ideals of scientific reasoning, particularly for those steps of reasoning by which laws of nature are formulated on the basis of factual evidence, and by which the effect of new evidence on our confidence in the truth of laws is assessed.'

Harré 1986, p.35

'Science is a collection of well-attested theories which explain the patterns and regularities and irregularities among carefully studied phenomena.'

Harré 1986, p.62

'[Popper] would say that [scientific] research is conducted toward the finding and the testing of highly testable hypotheses, whereas I say that it is very often conducted toward the finding and the testing of metaphysically relevant hypotheses. And as a rule ... research tends to begin with hypotheses which have a low degree of testability or are not testable at all.'

Agassi 1975, p.219

'Empirical science manifests its empirical character more systematically than mathematics, and manifests other characteristics as well, which are lacking in mathematics.
But what about the claim that theories manifesting empirical character, i.e., refutable theories, also necessarily manifest the other characteristics of science, i.e., they have informative content, explanatory power, simplicity, abstractness, generality, and precision? I simply reject this claim.

*Agassi 1975, p.218*

S.43 'The aim of science is to attempt to comprehend the world rationally, as we all agree (including the positivists who should disagree). But this is too vague. What is the rational method and what is comprehension? Rationality, said Popper, is manifest in empirical tests. He later generalised this: the rational method is the critical method. Is metaphysics rationally debatable? Yes.'

*Agassi 1975, p.219*

S.44 'The history of science, in so far as it is a history of scientific progress, consists not so much in the progressive accumulation of facts as the progressive clarification of problems. What makes a natural scientist is not his knowledge of facts about nature but his ability to ask questions about nature: first, to ask questions at all, instead of waiting to see what turns up; and secondly, to ask intelligent questions, that is, answerable questions: intrinsically answerable questions, as distinct from nonsensical questions …'

*Collingwood 1945, p.42*

S.45 'The sciences are regional ontologies and ontology is general science. After all, every substantive scientific problem is a subproblem of the problem of ontology, to wit, *What is the world like?*

*Bunge 1977, p. xiii*

S.46 'Every science studies systems of some kind, whether natural (physical, chemical, biological, or social) or artificial (technical). Moreover most sciences study nothing but systems. Thus biology studies biosystems, sociology social systems, and technology technosystems. Physics seems to be the only science that investigates not only systems, such as atoms and large scale fields, but also putatively simple or elementary things such as electrons and photons. Even so, physicists acknowledge that every such basic thing is a component of some system or other.

*Bunge 1979, p.1*

S.47 'From the perspective of the standard view [of science, some version of which having been adopted by most sociologists of knowledge], the natural world is to be regarded as real and objective. Its characteristics cannot be determined by the preferences or intentions of its observers. These characteristics can, however, be more or less faithfully represented. Science is that intellectual enterprise concerned with providing an accurate account of the objects, processes and relationships occurring in the world of natural phenomena. To the extent that scientific knowledge is valid, it reveals and encapsulates in its systematic statements the true character of this world. As Galileo puts it: “the conclusions of natural science are true and necessary, and the judgement of man [sic] has nothing to do with them”. Although the natural world is, in a certain sense, undergoing, continuous change and movement, there exist underlying and unchanging uniformities. These basic empirical regularities can be expressed as universal and permanent laws of nature, which tell us what is always and everywhere the case. Unbiased, detached observation furnishes the evidence on which on which these laws are built. The creation of scientific knowledge “begins with the plain and unembroidered evidence of the senses, with innocent, unprejudiced observation ... and builds upon it a great mansion of natural law” (Medawar). Indeed, observational laws are no more than general propositions summarising a body of reliable factual evidence. The validity of the factual foundation of scientific knowledge can be guaranteed with a high degree of confidence because science has evolved stringent criteria, for example, in connection with experimental procedures, by means of which empirical knowledge claims are evaluated and their accurate representation of empirical phenomena is ensured. Thus accepted scientific knowledge, because it has satisfied these impersonal, technical criteria of adequacy, is independent of those subjective factors, such as personal prejudice, emotional involvement and self-interest, which might otherwise distort scientific perception of the external world.'

*Mulkay 1979, pp. 19-20*
S.48 'In pure or basic science - that somewhat ephemeral category of research undertaken by men whose most immediate goal is to increase understanding rather than control of nature - the characteristic problems are almost always repetitions, with minor modifications, of problems that have been undertaken and partially resolved before.'

*Kuhn, in Boyd et al., (eds) 1991, p.143*

S.49 'We use the word "science" here in its widest sense, including all the theoretical knowledge, no matter whether in the field of natural sciences or in the field of the social sciences and the so-called humanities, and no matter whether it is knowledge found by the application of special scientific procedures, or knowledge based on common sense in everyday life ... What is usually called science is merely a more systematic continuation of those activities which we carry out in everyday life in order to know something.

The first distinction which we have to make is that between *formal science* and *empirical science*. Formal science consists of the analytic statements established by logic and mathematics; empirical science consists of the synthetic statements established in the different fields of factual knowledge.'

*Carnap, in Boyd et al., (eds) 1991, pp. 394-5*

S.50 'Truisms from empiricist philosophy of science often turn out to be false, but one such truism is certainly true: Scientific knowledge is experimental knowledge. It is characteristic of scientific research that observational evidence plays a crucial role in the resolution of the issue between contending hypotheses, and whatever sort of objectivity scientific inquiry has depends crucially on this feature of the scientific method. It may be disputed what the limits of experimental knowledge are, or how theory-dependent observations are, or how conventional or "constructive" scientific objectivity is, but it is not a matter of serious dispute that the remarkable and characteristic capacity scientific methodology has for the resolution of disputed issues and for the establishment of instrumental knowledge is strongly dependent upon the special role it assigns to observation.'

*Boyd, in Boyd et al., (eds) 1991, p.349*

S.51 'The topic of discovery dominates the imagination of scientists in their working lives as well as that of students of science in their studies; as N. R. Hanson notes, "discovery is what science is all about". It would appear that the primacy of discovery is derived from the ambitions of the field from which it arises. Science, that peculiar culture which is the hallmark of Western civilisation, makes the discovery or uncovering of nature its central focus.'

*Brannigan 1981, p.1*

S.52 'For Newton ... science was composed of laws stating the mathematical behaviour of nature solely - laws clearly deducible from phenomena and exactly verifiable in phenomena - everything further is to be swept out of science, which thus becomes a body of absolutely certain truth about the doings of the physical world. By his intimate union of the mathematical and experimental methods, Newton believed himself to have indisputably allied the ideal exactitude of the one with the constant empirical reference of the other. Science is the exact mathematical formulation of the processes of the natural world.'

*Burtt 1932*

S.53 'These ... are the ethical principles inherent in scientific practice: the conviction that there exists objective truth; that there exist rules of evidence for discovering it; that, on the basis of this objective truth, unanimity is possible and desirable; and that unanimity must be achieved by independent arrivals at convictions - that is, by examination of evidence, not through coercion, personal argument or appeal to authority ... Science, like all other systems of thought, seeks answers to questions which men hold to be of importance. But whereas, in other outlooks, answers are accepted that harmonise with particular world-views peculiar to different cultural complexes, science seeks answers which are reducible to everyone's experience.'

*Rapoport 1957, pp. 796ff*

S.54 'The word "science" is used in two different ways. On the one hand it refers to a body of knowledge, and on the other to a set of rules by which this knowledge is to be collected. In neither sense is the meaning of the word clear cut ... but [there is] a fairly widespread consensus of opinion as to what science really is ... A dictionary definition of science might be something along the following lines: "Knowledge of the real world ascertained by observation, critically examined and classified systematically under general principles." In broad, somewhat idealistic terms, we can say that
this knowledge should provide an explanation of what is of value in past discoveries and it should also make some prediction of future events. Furthermore, it should promote scientific research (new discovery) by providing concepts which give a sense of understanding of the causes of events in the world and which help to communicate this understanding to others. Scientific knowledge should be universal in the sense of independent of space and time; it should be presented explicitly so as to be intelligible to all qualified practitioners; and it should have empirical relevance such that all can evaluate the correspondence between its theories and their practical implications.'

Richard 1987

S.55 '[The economist] Galbraith himself attacks what he sees as the outmoded image of science still held by many people, an image that may have fitted the nineteenth century when it was “the product of the individual efforts of men of genius”, but which is quite inappropriate for modern science which is “a highly organised new profession closely linked with industry and government.” Its success has been achieved by “taking ordinary men, informing them narrowly and deeply and then, through appropriate organisation, arranging to have their knowledge combined with that of other specialised but equally ordinary men.”'

Richard 1987, p.128

S.56 ‘...modern science has become inextricably linked with politics, while yet remaining unanswerable to those whose lives are affected by its actions.’

Richard 1987, p.183

S.57 'Ron Giere suggests that the success of science is due to causal interaction between scientists and the external world. This is similar to an earlier idea of Bas van Fraassen, who writes: science is a biological phenomenon, an activity by one kind of organism which facilitates its interaction with the environment... I claim that the success of science is no miracle... For any scientific theory is born into life of fierce competition... Only the successful theories survive - the ones which in fact latched onto actual regularities in nature.

In this passage, van Fraassen is referring to empirical success. Whilst the level of empirical adequacy is of major importance to the assessment of any theory, it is not the sole consideration. In cases of rival theories, which are underdetermined by the available data, empirical success does not assist in making a choice between these theories at all.'

Riggs 1992, p.174

S.58 'There is, of course, more to the success of science than mere empirical success. In order not to “beg the question” of the success of science and to avoid his account being labelled as normative, Laudan outlines a set of goals for scientific research which are concerned with particular cognitive features. The success of science, he argues, can then be gauged on the basis of how well science can be said to have reached these cognitive goals. Laudan writes:

These goal states concern themselves with certain interesting epistemic and pragmatic attributes. Consider a typical list of some of these aims:

a) to acquire predictive control over those parts of one’s experience of the world which seem especially chaotic and disordered;

b) to acquire manipulative control over portions of one’s experience so as to be able to intervene in the usual order of events so as to modify that order in particular respects;

c) to increase the precision of the parameters which feature as initial and boundary conditions in our explanations of natural phenomena;

d) to integrate and simplify the various components of our picture of the world, reducing where possible to a common set of explanatory principles.

If we define cognitive “success” along these lines, then it seems uncontroversial to say that portions of the history of science in the last 300 years have been a striking success story.'

Against such criteria as this, science has indeed been successful. The question is “why”? Laudan offers a more plausible explanation than Bas van Fraassen’s proposal of theory elimination by “natural selection”. Laudan’s argument is that the various methods of theory testing and of theory selection employed by scientists are such that they produce reliable theories over time. Those theories which we come to call “scientific” are efficient at advancing our cognitive aims and, in general, they do so better than theories we denote as “non-scientific”.'

Riggs 1992, pp. 174-5
Appendix A: Figure A.1

'Science is a problem-solving sub-culture whose main value is truth. It is concerned with developing testable statements about the world which in turn create images of the world which correspond to what the world is really like. Problem-solving, therefore, is the main preoccupation of scientists and indeed of the professionals in general whether they be doctor, engineer, architect, or planner.'

Boulding 1975, Editorial

'The aim of physical science is to establish highly general laws and theories applicable to the world. The extent to which those laws and theories are indeed applicable to the world is to be established by pitching them against the world in the most demanding way possible given the existing practical techniques. Further, it is understood that the generality and degree of applicability of laws and theories is subject to continual improvement.'

Chalmers 1990, p.7

'The history of scientific thought ... is the history of a vision explored and controlled by argument. It is a vision and an argument initiated by ancient Greek philosophers, mathematicians and physicians in their search for principles at once of nature and of argument itself. By natural science we mean then a specific vision, created within Western culture, at once of knowledge and of the object of that knowledge, at once of natural science and of nature. We may trace the characteristically Western tradition of rational science and philosophy to the commitment of the Greeks, for whatever reason, to the decision of questions by argument and evidence, as distinct from custom, edict, revelation, authority or whatever else. Of course all people as rational beings may decide questions by argument and evidence. It was the Greek style of rationality to make this explicit by analysis of the reasoning involved, in the manner of Socrates. The Greeks developed thereby the conceptions of a problem as distinct from a doctrine. At the same time by deciding that, among the many possible worlds as envisaged in other cultures, the one existing world was a world of exclusively self-consistent and discoverable rational causality, they committed their scientific successors exclusively to this effective direction of thinking, and closed to them visions of things still open elsewhere. They introduced in this way the conception of nature, comprising a rational scientific system, in which formal reasoning matched natural causation, so that natural events and reasoned conclusions must equally follow exactly from true principles. Hence the two fundamental conceptions from which the characteristic style of all Western rational thinking has followed: causal demonstration and formal proof.'

Crombie 1993, p.2

'Philosophy and science were indistinguishable up to the end of the eighteenth century when Kant convinced the majority of philosophers that science could deal only with the world of appearance whereas philosophy dealt with the world of something called reality. There was never a more superficial divorce, for both partners kept reuniting and separating like so many couples who can neither live together nor live apart.'

Boas 1965, p.37

'[Philosophy] has amended the procedures of science ... It (philosophy) has taken over from physics a conception of a permanent and indestructible material world and inferred religious conclusions from the existence of that world. It has given to science certain rules, such as, "Nothing is made from nothing"; "Nature always follows the simplest course"; "Nature does nothing in vain"; and these and similar rules have determined the kind of scientific conclusions that would be acceptable ... Each of them is based on some metaphysical dogma, some dogma that is usually unexamined. It is unexamined because it had been part and parcel of collective thinking and seems self-evident.'

Boas 1965, pp. 40-41

'Although curiosity and the desire to generalise are the mainsprings of the scientific mind, yet clearly they cannot alone create a scientist: originality and intelligence and perseverance are necessities, and the finding of pleasure in the use of the hands in delicate manipulations is very nearly necessary.'

Baker 1943, reprinted in Baker 1975, p.81

'The aim of natural science, as Findlay has said, "is to acquire as complete a knowledge as possible of the material universe; of the objects, materials and phenomena and the relations between the phenomena which make themselves known to us or which we apprehend by means of our senses". By following this finely-stated aim a structure of knowledge is built up which,
as A. V. Hill remarks, "is approved by all sane men"; though it would be wise to add that only the same men who have studied it are in a position to give their approval. Approval is actually an understatement of the feelings of men towards that "body of valid ideas" which constitute science.'

Baker 1943, p.84

S.66 'Science, as Alexander has said, is not "a mere repetition of facts; that would be a chronicle and not science"'.

Baker 1943, p.84

S.67 'J. G. Crowther has defined science as "the system of behaviour by which man [sic] acquires mastery of the environment". We should laugh if a man set out to define "army" and gave a good definition of "navy" by mistake; yet this is exactly comparable to what Crowther has done. His definition is a good one, but not of science: it is a definition of technology ... one of the contrasted subjects is called science or pure science or fundamental science, and the other is called technology or applied science (or by those who distinguish between the two latter) technology and applied science ... Technology serves man's material needs directly, and his spiritual needs indirectly (by providing, e.g., the ink and paper used by writers and composers). The [principal] uses of science ... are two: to serve as an end in itself, like music, and to form a basis for technology.'

Baker 1943, p.85

S.68 'Basic research in the natural sciences and engineering is aimed at broadening the base of our knowledge of the natural world and of how we can use it, both for the sake of advancing that knowledge and to provide the background for the solution of recognised current or future practical problems.'

Australian Science and Technology Council (ASTEC) 1989, p. vii

S.69. 'Pure basic research is carried out without the goal of long term economic or social benefits, apart from the advancement of knowledge, and no positive efforts are made to apply the results to practical problems or to transfer the results to sectors responsible for its application. Strategic basic research is carried out with the expectation that it will produce a broad base of knowledge likely to form the background to the solution of recognised current or future practical problems.

There has been a long standing separation of scientific and industrial research in Australia which has resulted in a persistent tendency to classify research objectives either as advancing knowledge or as contributing to the immediate solution of an industrial problem. While there are occasional examples of discovery, development or application occurring in a linear fashion, a discovery more often contributes to an international matrix of information and understanding. It can result in a greater or lesser rearrangement of the whole matrix, but more usually just fills in a gap. The international knowledge base which is developed in this way can then be used to solve problems in a particular application.'

Australian Science and Technology Council (ASTEC) 1989, p.1

S.70 'The natural sciences and engineering are defined as the major fields of science (physical, chemical, biological, earth, engineering and applied, and agriculture) excluding the social sciences and humanities (which are concerned with the extension of knowledge about man [sic], culture and society).'

Australian Science and Technology Council (ASTEC) 1989, p.13

S.71 'At the heart of these questions [of funding research] are two opposing points of view. The first is that scientists know best how to do research and should be left alone to do it. The second is that most basic research is funded by the taxpayer and this investment should show some return which will tangibly benefit the country ... To generate trust on the part of research managers, the researchers will need to change their view of the aims of their research, and recognise that, unless they have a well developed international reputation, their chances of sustained funding will be improved if the reasons for following a particular line of research can be related to reasons outside of their narrow discipline. These reasons could include the following, which were prepared for the Bromley Report on Physics (1972) in the United States, based on criteria put forward by Alvin Weinberg:
- the ripeness of the area for exploration;
- the significance of the questions addressed;
- the potential for discovery of fundamental new laws;
the potential for discovery of generalisations of broad scientific applicability;
• the attractiveness of the area to the most able scientists;
• the potential stimulation of other sciences;
• the potential contribution to engineering, medicine, applied science;
• the potential contribution to technology;
• the potential for immediate applications;
• the potential contribution to the goals of society;
• the contribution to prestige and international cooperation;
• the contribution to national responsibilities;
• the contribution to public education.'
Australian Science and Technology Council (ASTEC) 1989, pp. 6-8

'S.72 'When we say that modern science developed only in Western Europe at the time of Galileo in
the late Renaissance, we mean surely that there and then alone there developed the fundamental
bases of the structure of the natural sciences as we have them today, namely the application of
mathematical hypotheses to Nature, the full understanding and use of the experimental method,
the distinction between primary and secondary qualities, the geometricalization of space, and the
acceptance of the mechanical model of reality. Hypotheses of primitive or medieval type
distinguish themselves quite clearly from those of the modern type. Their intrinsic and essential
vagueness always made them incapable of proof or disproof, and they were prone to combine in
fanciful systems of gnostic correlation. In so far as numerical figures entered into them, numbers
were manipulated in forms of "numerology" or number mysticism constructed a priori, not
employed as the stuff of qualitative measurements compared a posteriori.'
Needham 1969, p.14

'S.73 'In summary, first science is not an independent, value-free dissociated activity which can be carried
on apart from the rest of human life, because second, it is, on the contrary, the expression in a very
precise form of the species-specific human behaviour which centres on making plans. Third, there is
no distinction between scientific strategies and human strategies in guiding our long-term attack on
how to live and how to look at the world. Science is a world view based on the notion that we can
plan by understanding. Fourth, science is distinguished from magical views by the fact that it refuses
to acknowledge a division between two kinds of logic. There is only one kind of logic; it works the
same way in all forms of conduct and it is not carried out by any kind of formula but by an active
view of how you apply the logic of long-term planning strategies to the conduct of the whole of your
life. Finally, and most crucially, science is distinguished from earlier forms of trying to achieve a
unitary view of the world by the fact that there is only one form of truth in it. There is no distinction
between man [sic] and nature, there is no distinction between the logic of magic and other logics, and
there is no distinction between means and ends.'
Bronowski 1978, pp. 17-18

'S.74 'First, science cannot be conceived as an isolated or independent activity because, second it must be
thought of as a world picture. This is how from now on we shall see the world until someone comes
up with an even more sophisticated view. And third, that world picture has the characteristic of being
active; it thinks of knowledge as being directed toward planned action, the human species-specific
concept on which it rests is that human beings are planners, that they guide their conduct by looking
ahead and making choices, and that science is an expression of that quite general human approach.
For that reason it is an integrated approach. You cannot in science, and this was my fourth point,
make any bifurcation and say this part of life is scientific and specialised and that is not nature
belongs here, man [sic] belongs there; or means belong here but ends stand above all that over there.
And finally, my fifth point - above all you cannot make a distinction between power and knowledge,
and that's the central distinction which magic makes. There is no way of doing science which is
magical.'
Bronowski 1978, pp. 19-20

'S.75 'Belief systems are not simply collections of norms which vary only in whether their substantive
focus is religion, morals, politics, etiquette, appropriate research procedures, or love-magic. They are
structures of norms which bear some relationship to each other and vary greatly in the degree to
which they are systematic. What is systematic about belief systems is the interrelatedness of the
various substantive beliefs. Some systems are more tightly interrelated than others.
At one end of the continuum are belief systems that consist of a few tightly linked general
statements from which a fairly large number of specific propositions can be derived. Confronted by a
new situation, the believer may refer to the general rule to determine the stance he should take.
Science is an example of such a belief system. The principle of the experiment remains the same
regardless of the differences in empirical problems to which it is applied ... the rules of scientific method, being systematic, may be applied to all kinds of data without regard to their location. Thus, a high degree of system is in one sense an aid to diffusion of belief ...

System also has consequences for social control. To the degree that a system of beliefs is highly systematic, social control may be affected on the basis of informal sanctions and may be easily taught and learned. Belief systems with a relatively high degree of system seem to rely on rather general internalised standards to maintain social control - standards such as generalised codes of ethics (science) ... To learn part is to learn all.

... In any kind of belief system that has a high degree of system - a scientific theory, for instance - a change in one proposition requires adjustments in all others.'

Borhek & Curtis 1975, pp. 26-28

'Science accepts innovation, is systematic, and is intolerant. Much of the material scientists have produced for mass consumption consists of polemics against competing belief systems such as astrology, unidentified flying objects, folk medicine, and theological definitions of the nature of man [sic] and the creation of the world (Polanyi, 1958). Much of the dispute within the sciences is between the proponents of one paradigm or another and has the flavour of disputes between religious systems (Kuhn, 1970). Although science takes on innovations as a matter of principle, it is not tolerant of its competitors. Within the fraternity we are not tolerant of our competitors, although we seek out innovations within our own speciality.'

Borhek & Curtis 1975, pp. 30-31

'The separability of the abstract belief system from its concrete expression depends on the ability of persons not affiliated with the association or unspecialised structure that carried it socially to understand and use it. Almost inevitably, this implies that the more systematic and empirically relevant a belief system is, the greater the feasibility of preserving it as an abstract ideal apart from a given concrete expression. In other words, the more a belief system depends on a specific person or persons for interpretation, the less it can "stand alone". If its validation comes from empirical events and the ability to systematically relate propositions according to an internally consistent logic, it can be reconstructed and perpetuated by any social group with only a few hints. Science is such a belief system. The logic of experiment can be applied by anyone who knows it, regardless of his or her connection with one of the traditional science-carrying institutions.'

Borhek & Curtis 1975, p.118

'Science covers the broad field of human knowledge concerned with facts held together by principles (rules). Scientists discover facts and test these facts and principles by the scientific method, an orderly system of solving problems. Scientists feel that any subject which man [sic] can study by using the scientific method and other special rules of thinking may be called a science.

The sciences include: (1) mathematics and logic; (2) the physical sciences, such as physics and chemistry; (3) the biological sciences, such as botany and zoology; and (4) the social sciences, such as sociology and anthropology.'


'... science is in a sense a cultural artefact. A different society, with a different "cultural hypothesis" ... would have created a different science.'

Harman, 1988

'Science is
1. the state or fact of knowing; knowledge or cognizance of something specified or implied; also, knowledge (more or less extensive) as a personal attribute (in Theology and occasionally in Philosophy);
2a. knowledge acquired by study; acquaintance with or mastery of any department of learning;
2b. trained skill;
3a. a particular branch of knowledge or study; a recognised department of learning; often opposed to art;
3b. a craft, trade, or occupation requiring trained skill;
4. a branch of study which is concerned either with a connected body of demonstrated truths or with observed facts systematically classified and more or less colligated by being brought under general laws, and which includes trustworthy methods for the discovery of new truth within its own domain;
5a. the kind of knowledge or intellectual activity of which the "sciences" are examples. In early use, with reference to sense 3: What is taught in the Schools, or may be learned by study. In modern
use chiefly: The sciences (in sense 4) as distinguished from other departments of learning; scientific doctrine or investigation;

5b. in modern use, often = "Natural and Physical Science";
5c. formerly applied to the portions of ancient and modern philosophy, logic, etc., included in the study for a degree in the School of Literae Humanaiores (Oxford University).'

*The Shorter Oxford English Dictionary on Historical Principles 1973*

S.81 ‘STS [Science and Technology Studies] is really a bunch of related academic subjects - such as history of science, technology policy, sociology of science, philosophy of science, economics of technological innovation, etc. They have all come together to apply social science and humanities techniques to understand science and technology as human, social, political institutions with complicated histories and relations to the rest of society.’

*Schuster 1993, p.1*

S.82 ‘... the commonsensical and 2500 year old story that what makes science work is the proper use of a thing called scientific method ... [which entails] a set of assumptions that have always underpinned and guided Western thinking about scientific method ...

"Science Discovers" Means:

(1) "Science Establishes Truths About Nature". How? By the use of the Scientific Method, which is based on the following assumptions:

1. Nature is an objective system of facts.
2. Humans can objectively observe and report facts.
3. Scientific knowledge is based on facts alone.
4. Theories are generalisations of facts and are proven true or "confirmed" by tests.
5. Science makes progress: Collecting more facts and successfully testing truer and more powerful theories.
6. Scientific knowledge is objective and proven, and therefore has no social, personal or political bias. So therefore

(2) “What Science Proves True about Nature is the Sole Basis for Technology and Social Progress.”’ [sic]

*Schuster 1993, pp. 3-6*

S.83 ‘...all the talk about scientific method is one vast cultural myth. Now, myths are important in how a society or institution works. We should not use the term myth in a derogatory way. Myths are not nonsense - they are very, very important. Within a given society, even our own, there are myths that help explain the nature and purpose of important social practices. And a myth often takes the form of being a very emotive and convincing story about how that institution or that practice got started, or how it works.

Now in the West we pride ourselves on being scientific and "rational" and so maybe we have less myths than other societies. That is what we have been taught in the West since, well, the 18th century. We have science, so we don’t need myths. Well, I’m going to suggest that the story of scientific method may be one of the most important constitutive myths of the modern West. In fact it is the myth that there are no myths, because we have science instead. In other words, the scientific method may be a kind of mythic story that Westerners tell each other in order to explain why there is Western science and what Western science is - so they can believe in Western Science, so they can feel comfortable with Western Science.

This leads to the points about which I do not wish to be misquoted. Stewart Russell introduced you to the notion of science and technology as "black boxes" in the engineering sense - social scientists and arts scholars have backed away from examining the inside workings of science and technology and have just looked at inputs and outputs. I’m going to suggest that the story of scientific method has helped to cause this - because it is like a shield or barrier around science hiding from us the real nature of what goes on inside the black box. Hiding from us that science is a messy, complex human historical institution, which has been shaped, and is shaped by cultural, economic and ideological forces. Science is, in Stewart’s words, a seething mass of social-political contention.’ [sic]

*Schuster 1993, p.11*

S.84 ‘...discoveries in science - all discoveries in science - have a structure [which is] linkages of certain changes of existing theory with certain specified material practices - they are not just new ideas, or are they the uncovering of "things" waiting around in nature by themselves to uncovered, "found", "discovered" by scientists. Discoveries are the association of slightly changed theory with certain material procedures. Discoveries have to do with human interaction with nature, and with human imposing of grids on nature - a discovery occurs when a change a human ideas, a change of human
S.85 ‘The entire scientific enterprise can be seen as the search for algorithmic compressions of observational data. The goal of science is, after all, the production of an abbreviated description of the world based on certain unifying principles we call laws. “Without the development of algorithmic compressions of data,” writes Barrow, “all science would be replaced by mindless stamp collecting - the indiscriminate accumulation of every available fact. Science is predicated upon the belief that the Universe is algorithmically compressible and the modern search for a Theory of Everything is the ultimate expression of that belief, a belief that there is an abbreviated representation of the logic behind the Universe’s properties that can be written down in finite form by human beings.”’ [sic]

Davies 1992, p.136

S.86 ‘The popularity of "holistic science" in recent years has prompted a string of books, most notably Fritjof Capra’s The Tao of Physics, that stress the similarities between ancient Eastern philosophy, with its emphasis on the holistic interconnectedness of physical things, and modern nonlinear physics. Can we conclude that Oriental philosophy and theology were, after all, superior to their Western counterparts? Surely not. We now appreciate that scientific progress requires both reductionistic and holistic approaches. It is not a question of one being right and the other wrong, as some people like to assert, but the need for two complementary ways of studying physical phenomena. What is interesting is that reductionism works at all. Why is it that the world is structured in such a way that we can know something without knowing everything? ...

The rise of science and the Age of Reason brought with it the idea of a hidden order in nature, which was mathematical in form and could be uncovered by ingenious investigation. Whereas, in primitive considerations of cause and effect, direct connections are immediately apparent to the sense, the laws of nature discovered by science are altogether more subtle. Anyone can see, for example, that apples fall, but Newton’s inverse-square law of gravitation demands special and systematic measurement before it is manifested. More important, it demands some sort of abstract theoretical framework, evidently of a mathematical nature, as a context for those measurements. The raw data gathered by our senses are not directly intelligible as they stand. To link them, to weave them into a framework, evidently of a mathematical nature, as a context for those measurements. The raw data gathered by our senses are not directly intelligible as they stand. To link them, to weave them into a framework of understanding, requires an intermediary step, a step we call theory.’

Davies 1992, pp. 78-9

S.87 ‘Spinoza was a pantheist, who regarded objects in the physical universe as attributes of God rather than as God’s creation. By identifying God with nature, Spinoza rejected the Christian idea of a transcendent deity who created the universe as a free act. On the other hand, Spinoza was no atheist: he believed he had logical proof that God must exist. Because he identified God with the physical universe, this amounted to a proof that our particular universe must also exist. For Spinoza, God had no choice in the matter: “Things could not have been brought into being by God in any manner or in any order different from that which has in fact obtained,” he wrote.

This type of thinking - that things are as they are as a result of some sort of logical necessity or inevitability - is quite common today among scientists. Mostly, though, they prefer to drop God out of it altogether. If they are right, it implies that the world forms a closed and complete system of explanation, in which everything is accounted for and no mystery remains. It also means that in principle we need not actually observe the world to be able to work out its form and content: because everything follows from logical necessity, the nature of the universe would be deducible from reason alone ... If such a closed explanatory system were even possible, it would profoundly alter our thinking about the universe and our place in it. But do these claims of completeness and uniqueness have any foundation, or are they just a vague hope?

Underlying all these questions is a crucial assumption: that the world is both rational and intelligible. This is often expressed as the “principle of sufficient reason,” which states that everything in the world is as it is for some reason. Why is the sky Blue? Why do apples fall? Why
are there nine planets in the solar system? We are not usually satisfied with the reply: "Because that's just the way it is." We believe that there must be some reason why it is like that. If there are facts about the world that must simply be accepted without reason (so-called brute facts), then rationality breaks down and the world is absurd.

Most people accept the principle of sufficient reason without question. The entire scientific enterprise, for example, is built upon the assumed rationality of nature. Most theologians also adhere to the principle, because they believe in a rational God. But can we be absolutely sure that the principle is infallible? ... Of course, if the principle is false, then further inquiry into ultimate issues becomes pointless.'

Davies 1992, pp. 161-2

S.88 '... the question of the reliability of scientific knowledge has become a serious intellectual issue. Once we have cast off the naive doctrine that all science is necessarily true and that all true knowledge is necessarily scientific, we realise that epistemology - the theory of "the grounds of knowledge" is not just an academic philosophical discipline. Very practically, in matters of life and death, our grounds for decision and action may eventually depend on understanding what science can tell us, and how far it is to be believed.

But what is science? How is it to be distinguished from other bodies of organised, rational discourse, such as religion, politics, law, or "the humanities"? In an earlier work, I have tried to show that scientific knowledge is the product of a collective human enterprise to which scientists make individual contributions which are purified and extended by mutual criticism and intellectual cooperation. According to this theory the goal of science is a consensus of rational opinion over the widest possible field.

From this point of view, much can be understood about the ways that scientists are educated, choose research topics, communicate with one another, criticise and refine their findings, and relate to one another as members of a specialised social group. The "consensus principle" thus leads directly into what is now called the internal sociology of the scientific community. From there we naturally proceed to investigate the place of science in society at large, trying to throw light on such important practical questions as the economics of research and development, the organisation of scientific institutions, priorities and planning of research, and the agonising ethical dilemmas facing the socially responsible scientist.'

Ziman 1978, pp. 2-3

S.89 'Let us enquire ... whether science as we know it is as universal and as unique as we often claim. Is there evidence about humankind, about society, or about science itself, that might suggest the contrary? Could our doubts be confirmed by the discovery that science is different in different epochs, in different cultural settings?

Unfortunately, modern science is monolithic and monopolistic. "Western" science as we know it has unique roots in seventeenth-century Europe and has effectively eliminated all competitors. Apart from its own self-critical activity, it has not been seriously challenged on its own grounds by an independent body of knowledge developed in a quite separate human society.'

Ziman 1978, pp. 109-110

S.90 '... modern science is unique as a social institution. In no other civilisation was there a comparable system of mutually communicating, criticising and socially-interacting observers, dedicated to the principles of consensibility and consensuality.'

Ziman 1978, p.110

S.91 'Ideally, scientific knowledge is stored and communicated in a variety of more or less artificial and formalised languages, or as reproducible material maps. But the doorway between the public noetic domain and the private mental domain of each individual is open in the first instance only to messages expressed in the natural language of his particular social group.'

Ziman 1978, p.111

S.92 'Strict application of the principles of sociology of knowledge seems to lead to the inescapable conclusion that science is no more than one of many competing world pictures in the noetic domain, and is not privileged by comparison with any other systematic scheme to which a social group can subscribe, such as the famous magical beliefs of the Azande. But total cultural relativism, like complete philosophical scepticism, is a sterile doctrine that inhibits further interesting and valuable investigations.

To escape from it, let us avoid the vulgar error that the essence of science lies in its most sophisticated results, its astonishing revelations of the nature of things, and the attendant metaphysical interpretations which contrast so dramatically with alternative, "non-scientific" world
pictures. It is sheer intellectual snobbery to fasten solely on those high-flown features of modern scientific knowledge, ignoring the mundane foundations on which they rest. Our model of science emphasises the whole corpus of consensual knowledge, which is not necessarily true in every detail, which may yet contain gross conceptual errors and fallacies, but which is not to be judged simply by inspection of its most extreme and schematised theoretical consequences.'
Ziman 1978, pp. 119-120

S.93 'The whole strategy of science is directed towards the creation of a maximum consensus in the public domain. Such a consensus must be based on, and held together by, a pre-existing mental harmony between independent human beings on at least some matters of common interest.'
Ziman 1978, p.124

S.94 'The philosophy of science is] a discipline in which the elements involved in scientific inquiry - observational procedures, patterns of argument, methods of representation and calculation, and metaphysical presuppositions - are analysed and discussed; and the grounds of their validity are evaluated from the points of view of formal logic, practical methodology, and metaphysics. The subject has been approached both with ontal preoccupations, with a concern for what kinds of entities can properly figure in scientific theories; and with epistemic interests, with a concern for the concepts and methods employed in studying natural and human phenomena.'

S.95 'Quite apart from anything else ... there is one very important aspect of science ... - the scientific method.
Science advances in a definite pattern. First and foremost scientists must make observations. These observations must be careful and accurate; and as the results of more and more observations accumulate in any one field they often seem to form a maze of complicated facts which are difficult to understand.

It is then, however, that the second important part of the scientific method is used. Scientists look at the results of all their observations and try to develop a theory or a model of how whatever it is they are investigating might work. A theory or model which is successful at the time is one which fits all the observed results and makes them seem quite natural. This model or theory can then be used to predict the results of new observations; if these turn out to be correct the model is further substantiated. If, on the other hand, new observations give results contrary to the model, then it must be either discarded in favour of a new model or discarded.

It is in this way that science advances.'
Messel (ed.) 1964, pp. 1-13,14

S.96 'There is no ... step by step scientific method which inexorably leads us to the truth, there never has been and there never will be!'
Messel (ed.) 1987, p.25

S.97 'Science can be thought of as systematic and formulated knowledge of natural phenomena which is based on particular methods of inquiry and thinking. The methods of inquiry are, at their best, firmly grounded in attitudes such as open-mindedness and impartiality, such as respect for data tempered with tentativeness about accepting results as final. Scientific methods of inquiry require a disciplined approach but not necessarily a lock-step one: often it is necessary to stand back from an investigation and take an overall view. This type of critical appraisal is a fundamental part of a scientific approach. Scientific ways of thinking are used to explain natural phenomena by the development of theoretical models and explanations. Science is a mixture of theoretical and practical methods centred around these particular ways of thinking.'
A.C.T. Schools Authority 1984, p.2

S.98 'In common usage, the word "science" is applied to a wide variety of disciplines or intellectual activities which have certain features in common. Usually a science is characterised by the possibility of making precise statements which are susceptible to some form of empirical verification.'
Education Commission of N.S.W. c.1987, p.2

S.99 'Despite the antiquity of the terms 'science' and 'philosophy', they acquired their present meanings only during the nineteenth century. With the benefit of hindsight, we can find much activity which we would call 'scientific' or 'philosophical' in earlier periods; but the respective practitioners did not see themselves as divided into distinct camps, or at least in a way we would recognise today. Generally, much of what we now call philosophy was tacitly accepted as a proper part of science (or 'philosophy' as it was then called), but contrasted with the useless 'school metaphysics' of the
universities. It was only when philosophy more or less as we now know it became a university specialism in the nineteenth century that it became possible for scientists to leave the more philosophical aspects of science to specialist philosophers.'
Ross 1990, p.814

S.100 'L.A. Richards attempted a less metaphysical answer to the same linguistic problem of what styles of belief are demanded by literary and scientific texts from the reader. He contrasts, without preference, the 'statements' of science and the 'pseudo-statements' of literature. Despite the derogatory connotations of 'pseudo', Richards is attempting a dry and clear distinction which will preserve the fullness of poetry. Statement (which we might now call propositional discourse) demands belief; pseudo-statement does not ...'
Beer 1990, pp. 788-9

S.101 'Carnap's philosophical, which is to say logical, analysis is practised on Einstein's theory as a product, an achievement that is given, with its structure and content complete, and needing, from the philosopher, only explication. Likewise, with those items, such as laws and theories, that are the characteristic structures of science in general Carnap takes these to be given. Indeed they are given in that they are definitively characteristic of all natural science, in that any process or programme of empirical, explanatory inquiry would only count as science if it were producing structures that comprise confirmable empirical laws and testable theoretical laws and therefore structures that constitute physical theories. Philosophical questions about processes and programmes resolve themselves, consequently, into logical questions about those structures.'
Hodge & Cantor 1990, p.843

S.102 'In highlighting the major shifts in the sociology of science I have suggested that it has been able to explore more successfully and interestingly the new directions in which science and technology are moving today. These 'new directions' are not simply of a cognitive or conceptual nature - new fields of research for example, such as biotechnology - but also of an institutional character: in fact, both feed back on each other, cognitive developments shaping and being shaped by institutional developments...
I argued that there are four main developments in science and technology today ... First, scientific labour inside the laboratory is typically being undertaken by interdisciplinary research teams or trans-laboratory networks whose research is less easily divided into the basic-applied dichotomy of the past ... Secondly, and as a direct result of the previous point, I have given considerable emphasis to the way in which science and technology have become less easy to distinguish in practice than in the past ... Thirdly, the commercial exploitation of scientific knowledge has become necessary for the survival of firms in certain industrial sectors of the economy, those that are likely to provide the new manufacturing processes and products of the twenty-first century, such as bioscience, information technology and new material sciences ... Finally, science and technology have become subject to a growing promotion, monitoring and regulation by national and international agencies.
Webster 1991, pp. 152-3

S.103 'Science is an ever-unfinished quest to discover facts and establish relationships between them. But let us go beyond this. While not trying to propose a one-sentence definition of the whole complex concept "science", we may perhaps agree at the outset that the main business of science is to trace in the chaos and flux of phenomena a consistent structure with order and meaning, that is, to interpret and to transcend direct experience. "The object of all sciences," in Einstein's words, "is to coordinate our experiences and to bring them into a logical system." And Niels Bohr agrees when he says "The task of science is both to extend the range of our experience and to reduce it to order."

Probably you will think these statements too all-inclusive; the same aim might well be claimed by art or by philosophy. Thus T. S. Eliot has said, "It is the function of all art to give us some perception of an order in life by imposing an order upon it," and A. N. Whitehead defined speculative philosophy as "the endeavour to frame a coherent, logical, necessary system of general ideas in terms of which every element of our experience can be interpreted." Indeed, in science, as in art and philosophy, our most persistent intellectual efforts are directed toward the discovery of pattern, order, system, structure, whether it be as primitive as the discernment of recurring seasons or as sweeping as a cosmological synthesis. In this sense, science is but one facet of the great intellectual adventure, the attempt to understand the world of experience in each of its aspects...

Of course, the fundamental and distinct differences separating the sciences from the nonsciences must not be denied. There are obvious points which set one apart from the other, for example, the motivations of the investigators...

Much more clear-cut than the first is a second point of difference between science and nonscience; it lies in the kind of concepts and rules the scientist uses, and the type of argument
which will cause him to say, “Yes, I understand and I agree.” This will occupy our attention to some
degree, as will a third point of difference: the observation that in the course of time, despite great
innovation and revolutions, there accumulates in science a set of internationally acceptable, basic, and
fairly enduring conceptual schemes, whereas this can hardly be said for many other human
endeavours...

All too often the suggestion is made that the successes of science are the results of applying
“the scientific method.” But if by “scientific method” we mean the sequence and rule by which
scientists now and in the past have actually done their work, then two things become obvious. First,
as for every task, there are here not one but many methods and uncountable variants and, second, even
these different methods are usually read into the story after the work has been completed, and so
reflect the actual working procedures only in a rather artificial and debatable way.”
Holton & Roller 1958, pp. 214-216

S.104 ‘...it is essential to understand science as an historically evolving body of knowledge and that a
theory can only be adequately appraised if due attention is paid to its historical context. Theory
appraisal is intimately linked with the circumstances under which a theory first makes its
appearance.’
Chalmers 1982, p.35

S.105 ‘In the preceding discussion I argued that, as a result of the evolution of scientific thought, there has
emerged a broad and coherent picture of the universe and of life in it, a view which, while incomplete
and in some aspects open to serious question, is at present the best picture available. In the present
section I will argue that this process of unification has not been restricted to the integration of beliefs
about the world, but that there has also been a progressive tendency toward unification of those
beliefs with the methods employed to attain well-grounded beliefs. That is, I will argue, the methods
we consider appropriate for arriving at well-grounded beliefs about the world have come more and
more to be shaped by those very beliefs, and have evolved with the evolution of knowledge.

Such a view of the intimate relation between knowledge and the methods of gaining knowledge
flies in the face of the traditional sharp bifurcation of the two. For it is, and has long been,
commonly assumed that there exists a unique method, the “scientific” or “empirical” or
“experimental” method, allegedly discovered or at least first systematically applied in the seventeenth
century, which can be formulated wholly independently of, and is wholly unaffected by, the
knowledge which is arrived at by its means. It is as though scientific method is a set of abstract and
immutable rules, like the rules of chess, independent of the strategies of the game but governing
what strategies are possible.

Yet the most strenuous efforts of scientists and philosophers have failed to produce agreement as
to precisely what that method is. Indeed, general philosophical theories about science according to
which there is an eternal scientific method which, once discovered, needs only to be applied to
generate knowledge, but which itself will not alter in the light of that knowledge, have proved either
empty or false.’
Shapere 1984, p.178

S.106 ‘Such a major break as I am about to outline changes not only the sciences themselves but the whole
disposition of knowledge, discourse and practice in which the sciences inhere. The kind of knowledge
produced in any given scientific era is the outcome not only of the specific interaction of the sciences
but also of the relation of science to technology, philosophy, art and other intellectual and practical
concerns. Thus, for example, the relation between science and technology was very different during
the nineteenth century compared to now and was different again during the seventeenth century
compared with mediaeval times. So, too, the relations between the sciences alter with each change in
the overall character of the formation of knowledge. In every new period new constellations of the
sciences arise, only to be dispersed when knowledge changes again.’
Redner 1987, p.62

S.107 ‘The official conception of the present disposition of the sciences is largely anachronistic, though
still influential, for the university system is even now formally administered according to it.
Historically it derives from the latter phase of the Classical scientific era of the nineteenth and early
twentieth centuries ...

For some time, however, the departmental system has ceased to have any real cognitive relevance to
the actual research activities going on within university confines or outside in the research
institutions. For in the contemporary era of science this now Classic scientific disposition has lost its
meaning.’
Redner 1987, pp. 62-3
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S.108 'Each of the elements of the contemporary disposition of the sciences has been a long time in the making. Only the constellations are relatively new, that is, the conjunction of all these elements as a dominant system of sciences. We can trace each of the main characteristics of contemporary World science back into the nineteenth century; forms of technification, formalisation, abstraction, problem-solving and finalisation have always been there to some degree.'
Redner 1987, p.63

S.109 'For science, I will argue, is a social activity whose aim is the production of the knowledge of the kinds and ways of acting of independently existing and active things.'
Bhaskar 1975, p.24

S.110 'Science is no longer a marginal pursuit of little practical use carried on by a handful of enthusiasts; and it no longer needs to justify itself by a direct answer to the challenge of other fields of knowledge claiming exclusive access to the truth. As the world of science has grown in size and in power, its deepest problems have changed from the epistemological to the social. Although the character of the knowledge embodied in a particular scientific result is largely independent of the social context of its first achievement, the increase and improvement of scientific knowledge is a very specialised and delicate social process, whose continued health and vitality under new conditions is by no means to be taken for granted. Moreover, science has grown to its present size and importance through its application to the solution of other sorts of problems, and these extensions react back on science and become part of it. For an understanding of this extended and enriched "science", we must consider those sorts of disciplined inquiry whose goals include power as well as knowledge.'
Ravetz 1971, p.10

S.111 'There are, therefore, grounds for believing that science grows as it does, so much faster than mere people, because old knowledge breeds new. Furthermore, the key process seems to be that in which very recent knowledge breeds new so much faster than it does when it later becomes packed down into the archive. Science grows very regularly, in a very structured way, and from its epidermis rather than from its body. In terms of our present problem this model may be taken as giving a mechanism for the 'transfer' from old science to new science...
Perhaps one should emphasise that this is the normal growth pattern of scientific research and most published work occurs thus. What does not usually happen is the ab initio growth of new knowledge coming from almost nowhere. Only in that convenient mythology of science that historians spend their lives trying to dispel, does it appear that the mountain-peak contributions of Newton, Copernicus, and Galileo arose from the native genius of isolated minds. Innovation in the sort of knowledge that is published in scientific papers arises when new facts, new experiments, new theories are added to the immediately preceding old ones in a very structured way. Transfer, from outside the knowledge of men is a rare thing, though it may be very important when it happens. I hazard a guess, however, that even when some outside force, like the invention of the cyclotron, makes knowledge growth burst out in new ways, it does so only in retrospect as we attribute a magnified power to the single great event and forget the less dramatic build-up of the host of related researches clustered around the clear main line.'
de Solla Price 1972, pp. 168-9

S.112 'We have been talking about science in a way such that there is an implicit definition for it. Science, to fit this model, must consist of the scientific papers that are being cited, counted, and otherwise manipulated in such studies. I therefore propose, as a formal definition, to take science as that which is published in scientific papers. We may define these in turn, either crudely as articles in journals in the World List of Scientific Periodicals, or more artfully by making use of the knitted research-front structure. We may suppose quite reasonably (and the evidence bears it out) that the structure is what makes science different from the nonscientific scholarship that is published in other periodicals that are probably not in the World List.'
de Solla Price 1972, p.170

S.113 'Scientific theories are ways of looking at the world; and their adoption affects our general beliefs and expectations, and thereby also our experiences and our conceptions of reality. We may even say that what is regarded as 'nature' at a particular time is our own product in the sense that all the features ascribed to it have first been invented by us and then used for bringing order into our surroundings.'
Feyerabend 1962, as quoted by Suppe 1979, p.178

S.114 'Four sets of institutional imperatives - universalism, communism, disinterestedness, organised scepticism - comprise the ethos of modern science.
Universalism
Universalism finds immediate expression in the canon that truth claims, whatever their source, are to be subjected to preestablished impersonal criteria: consonant with observation and with previously confirmed knowledge. The acceptance or rejection of claims entering the lists of science is not to depend on the personal or social attributes of their protagonist; his [sic] race, nationality, religion, class and personal qualities are as such irrelevant. Objectivity precludes particularism. The circumstance that scientifically verified formulations refer to objective sequences and correlation militates against all efforts to impose particularistic criteria of validity...

Communism

"Communism", in the non-technical and extended sense of common ownership of goods, is a second integral element of the scientific ethos. The substantive findings of science are a product of social collaboration and are assigned to the community. They constitute a common heritage in which the equity of the individual producer is severely limited ... Given such institutional emphasis upon recognition and esteem as the sole property right of the scientist in his discoveries, the concern with scientific priority becomes a 'normal' response ... The institutional conception of science as part of the public domain is linked with the imperative for communication of findings. Secrecy is the antithesis of this norm; full and open communication its enactment ...

Disinterestedness

Science, as is the case with the professions in general, includes disinterestedness as a basic institutional element. Disinterestedness is not to be equated with altruism nor interested action with egoism. Such equivalences confuse institutional and motivational levels of analysis. A passion for knowledge, idle curiosity, altruistic concern with the benefit to humanity and a host of other special motives have been attributed to the scientist. The quest for distinctive motives appears to have been misdirected. It is rather a distinctive pattern of institutional control of a wide range of motives which characterises the behaviour of scientists. For once the institution enjoins disinterested activity, it is to the interest of scientists to conform on pain of sanctions and, in so far as the norm has been internalised, on pain of psychological conflict ... Involving as it does the verifiability of results, scientific research is under the exacting scrutiny of fellow-experts ... The demand for disinterestedness has a firm basis in the public and testable character of science and this circumstance, it may be supposed, has contributed to the integrity of men of science ... In this connection, the field of science differs somewhat from that of other professions. The scientist does not stand vis-à-vis a lay clientele in the same fashion as do the physician and lawyer, for example. The possibility of exploiting the credulity, ignorance and dependence of the layman [sic] is thus considerably reduced. Fraud, chicane and irresponsible claims (quackery) are even less likely than among the 'service' professions ...

Organised scepticism

... [O]rganised scepticism is variously interrelated with the other elements of the scientific ethos. It is both methodologic and an institutional mandate. The suspension of judgement until 'the facts are at hand' and the detached scrutiny of beliefs in terms of empirical and logical criteria have periodically involved science in conflict with other institutions. Science which asks questions of fact, including potentialities, concerning every aspect of nature and society may come into conflict with other attitudes towards these same data which have been crystallised and often ritualised by other institutions ... This appears to be the source of revolts against the so-called intrusion of science into other spheres. Such resistance on the part of organised religion has become less significant as compared with that of economic and political groups. The opposition may exist quite apart from the introduction of specific scientific discoveries which appear to invalidate particular dogmas of church, economy or state. It is rather a diffuse, frequently vague, apprehension that scepticism threatens the current distribution of power.'

Merton, 1942, republished in Merton 1967, pp. 551-61

S.115 'Every science (in so far as we take this word to refer to the content and not to the human arrangements for arriving at it) is a system of cognitions, that is, of true experiential statements. And the totality of sciences, including the statements of daily life, is the system of cognitions. There is, in addition to it, no domain of "philosophical" truths. Philosophy is not a system of statements; it is not a science.'

Schlick, in Ayer (ed.) 1959, p.56

S.116 'Science provides the best example of a rational endeavour, and it has long been held that the scientific practice conforms to the classical model of rationality. Recent work in the history and philosophy of science cast considerable doubt of this second claim, and this, in turn, has led to surprising new questions about the rationality of science, while adding fuel to doubts about the viability of any notion of rationality ... I will argue that crucial scientific decisions are not rational when viewed in terms of the classical model, but that this should be read as a mark against the classical model of rationality, rather than as an argument against the rationality of science. The rationality of science will provide an important constraint on our attempts to construct a new model...
Appendix A: Figure A.1

Of rationality. This does not mean that the rationality of science is an *a priori* truth, but only that, at the present stage in the development of knowledge we have no clearer example of rational endeavour. Thus we might as well pay close attention to scientific practice in attempting to develop a model of rationality.

Brown 1977, p. vii

S.117 ‘On the one hand, a palpable sign of progress in the natural sciences is that, over time, the relevant units of criticism, such as particular claims and arguments, become smaller and more focussed. This is the phenomenon that Kuhn dubbed “normal science,” which presupposes that a community of inquirers share enough assumptions that they can devote their energies to solving well-defined puzzles. On the other hand, analytic philosophers have generally followed Carnap’s (1956) lead in holding that criticism can be rationally applied to issues raised within a conceptual framework, relative to its own standards, but not to issues raised about a framework, relative to some “transcendent” or “metaphysical” standards. Now combine these two points with an awareness that major network questions remain unresolved in philosophy, and the result is the pattern that criticism takes in contemporary analytic philosophy. It is a pattern quite unlike what one finds in the natural and social sciences. Analytic philosophers diligently solve puzzles even if they remain unconvinced that these puzzles are situated within the epistemically soundest framework available. Indeed, both Carnap and Popper are, strictly speaking, irrationalists when it comes to evaluating alternative conceptual frameworks prior to one’s being adopted.’

Fuller 1993, pp. 201-2

S.118 ‘Eisenhower implicitly focuses on the three basic aspects of all scientific work: the organisational, instrumental and cognitive - in short, people, machines and ideas. These can be ranked in this order of importance because the changes that brought about the contemporary epoch of science can be graded with this weighting scale. The most crucial changes took place in the organisation of science, that is, in the socio-political system and institutional arrangements under which science is produced. Next in importance were the changes in instrumentation, in the new technological machinery and the new techniques of research made available in all the sciences. Of least importance were the cognitive changes, the new theories, ideas and hypotheses, which, although altered, were largely developments of previous ones. This kind of weighting is more or less in historical conformity with the other major changes in contemporary, so-called advanced society where the ideological or cultural dimension is least altered and least developed whereas the technological and organisational dimensions are most pronounced.’

Redner 1987, p.17

S.119 ‘Scientific knowledge is ... social knowledge. It is produced by processes that are intrinsically social, and once a theory, hypothesis, or set of data has been accepted by a community, it becomes a public resource. It is available to use in support of other theories and hypotheses and as a basis of action. Scientific knowledge is social both in the ways it is created and in the uses it serves.’

Longino 1990, pp. 75-6

S.120 ‘As a professional scientist I am fully committed to the scientific method of investigating the world. I believe that science is an immensely powerful procedure for helping us to understand the complex universe in which we live. History has shown that its successes are legion, and scarcely a week passes without some new progress being made. The attraction of the scientific method goes beyond its enormous power and scope, however. There is also its uncompromising honesty. Every new discovery, every theory is required to pass rigorous tests of approval by the scientific community before it is accepted. Of course, in practice, scientists do not always follow the textbook strategies. Sometimes the data are muddled and ambiguous. Sometimes influential scientists sustain dubious theories long after they have been discredited. Occasionally scientists cheat. But these are aberrations. Generally, science leads us in the direction of reliable knowledge.

Davies 1992, p.14

S.121 ‘In common usage the word science is applied to a wide variety of disciplines or intellectual activities which certain features in common ... Usage is not, however, always unanimous as to whether some disciplines should always be called sciences or not, and there is often lively controversy as to the propriety of speaking of the social or historical sciences.

Usually a science is characterised by the possibility of making precise statements which are susceptible to some sort of check or proof. This often implies that the situations with which the special science is concerned can be made to recur in order to submit themselves to check, although this is by no means always the case. The observational sciences such as astronomy or geology in which repetition of a situation at will is intrinsically impossible, and the possible precision is
limited to precision of description. There is also usually the implication that the subject matter of the individual science is something in the world of phenomena. Thus it is not usual to speak of the 'science' of mathematics or the 'science' of logic, even though both these disciplines are capable of the highest precision.

A common method of classifying sciences is to refer to them as either exact sciences or descriptive sciences. Examples of the former are physics and, to a lesser degree, chemistry; and of the latter, taxonomical botany or zoology. The exact sciences are in general characterised by the possibility of exact measurement. Measurement is fundamentally description given by the use of numbers. Given the system of measurement and the measuring numbers for any special situation, that situation has been adequately described if it is possible to reconstruct a situation such that measurement on it gives the same numbers. Because mathematics operates to large extent with numbers, systems subject to exact measurement are also susceptible of mathematical analysis: this susceptibility is one of the most important characteristics of the exact sciences. One of the most important tasks of a descriptive science is to develop a method of description or classification that will permit precision of reference to the subject matter.'


'What is "Science"? Our whole approach ... depends on how we might be tempted to answer this question. But it is really much too grand a question to be answered in a few words. Conventional definitions of science tend to emphasise quite different features, depending upon the point of view. Each of the metascientific disciplines - the history of science, the philosophy of science, the sociology of science, the psychology of creativity, the economics of research, and so on - seems to concentrate upon a different aspect of the subject, often with quite different policy implications.

For example, if science is defined as 'a means of solving problems', this emphasises its instrumental aspect. Science is thus viewed as closely connected with technology, and hence an appropriate subject for economic and political study. The implication that this instrument should be used wisely and well puts it into the open arena of social conflict.

Another definition of science - as 'organised knowledge' emphasises its archival aspect. Information about natural phenomena is acquired by research, organised into coherent theoretical schemes, and published in books and journals. Although this knowledge is often profoundly influential through its technological applications, there is much to be said for treating it as a politically neutral, public resource. The accumulation of scientific knowledge is thus a significant historical process, worthy of special study.

Or we may follow an old philosophical tradition by emphasising the methodological aspect of science. Procedures such as experimentation, observation and theorising are considered elements of a special method for obtaining reliable information about the natural world. From this point of view, science may be regarded as essentially objective, and hence transcending all political considerations.

Finally, one might emphasise the vocational aspect of science by tacitly defining it as 'whatever is discovered by people with a special gift for research'. This draws attention to such important personal aptitudes as curiosity and intelligence, which are well worth psychological investigation. Such studies might suggest that scientists should be recognised as members of a distinct profession, of considerable political significance.

There is so much that can be said about science from each of these and from other aspects that there is a tendency within each metascientific discipline to treat its own special definition as self-sufficient. Thus, philosophers of science largely ignore its instrumental and vocational features, whilst many serious studies of the political role of science seem quite oblivious to its complex methodological and vocational aspects. It is instructive to read books about science in this light. It almost seems as if each discipline has in mind a different 'model' of science, constructed around just those particular features in which it happens to be interested.

In truth, science is all these things, and more. It is indeed the product of research; it does employ characteristic methods; it is a body of organised knowledge; it is a means of solving problems. It is also a social institution; it needs material facilities; it is an educational theme; it is a cultural resource; it requires to be managed; it is a major factor in human affairs. Our "model" of science must relate and reconcile these diverse and sometimes contradictory aspects.'

Ziman 1984, pp. 1-2

'S But is the following not an intuitively plausible view of the development of science: that science is precisely the discipline, par excellence, of determining relations of relevance and irrelevance? The development of science consists, in large part, of beginning with suppositions about what is and is not relevant to a certain claim, and of gradually refining the claim and our understanding of what is relevant to it and what is not: of shedding certain beliefs as irrelevant; of introducing new ones which we find to be more so; of refining our modes of conceiving and describing the world around us so as to bring out more clearly and firmly the ways in which things are related to one another; of finding
out what is a relevant consideration for the acceptance or rejection of specific beliefs, and even of finding out that we must stick to the relevant.

According to this picture of science, we do not have in advance unalterable criteria of relevance, of what is to count as a reason. We arrive at new ideas, which enable us to do new things; and we elevate the considerations which led us to those ideas to the status of reasons, and the more general character of that reasoning to the status of criteria of reasoning, to be tested further in terms of their success. As for success, the situation is similar: far from having or needing transcendent and unalterable criteria of what is to count as successful, we find that we can do things with certain approaches (things we may not even have thought of beforehand), and then elevate certain general aspects of those new approaches to the status of criteria of success and ways of looking for further successes. We found, in the sixteenth and seventeenth centuries, that we could understand material substances in terms of what they are made of rather than in terms of their perfectibility; and looking for constituents then became a standard method and criterion of success in understanding material substances.

The process of developing such standards or criteria is far more complex than past and prevailing philosophies of science have assumed. It must consist partly in a revision of our descriptive language to bring out better what we have learned; it must consist further of revisions in our ways of learning about nature; and it must consist of much else as well. But to put it as simply as possible, it must consist not only of our coming to know about the world (the traditional focus of the theory of knowledge); it must also consist of learning how to learn, to think, and to talk about nature; it must, in short, consist of gradually coming to understand how to understand - of gradually reasoning our what it is to reason - of learning what it is to learn. We may, of course, always turn out to have been wrong or misguided or confused in the beliefs we have arrived at, or the standards of rationality we have forged, or the understanding we have developed of what it is to understand: to abandon the Principle of [Inviolable Beliefs] is to abandon the offer of guarantees; the best we can have in the way of what we take to be knowledge and reasons are, simply, the best we have arrived at in our searches; and even what we take to be ‘best’ is a hypothesis which may be debatable and may be rejected later in the light of what we then come to accept as reasons for doubt. The possibility of doubt and error is always open; but we do have, or at least develop, better and worse hypotheses about what are better and worse hypotheses, methods, descriptions, and so on.

Shapere 1984, pp. 416-7

S.124

'Science is not a homogeneous set of activities. There is science for understanding and science for manipulation, and while they merge into one another, and the former frequently now provides the basis for the latter, their styles and motivation are different. Science for understanding is an expression of human curiosity, the need to devise an intellectually graspable model of the natural world which enables us to find our way around in it, to think about it coherently and to realise how the things we observe 'hang together'. Emotionally the development of such intellectual models derives from the sense of wonder in the face of nature and has much in common with the creative work of artists. The tests by which the models are judged are concerned not only with their compatibility with observed facts and their powers of prediction but with their simplicity and elegance - tests which are essentially aesthetic...

Science in this sense of the search for understanding, does not, in my view, need to be justified by the greater power it confers on humankind. It is its own justification as a source of enlightenment and liberation: as a noble expression of the human spirit. A society which fails to give it opportunity and scope will thereby be the poorer. And a society which demands of its practitioners that they subordinate their imagination to the priorities of the accountant, the official and the military machine will destroy their creativeness as surely as if it imprisoned them in concentration camps.

This is not to suggest that science motivated by the desire to manipulate aspects of the world in which we live has nothing in common with science for understanding or that it does not have a legitimate place among human’s activities, but rather that their purposes are different, the attitudes of mind of those who practise them may well conflict, and above all that science for manipulation must be justified by its results. It should be required to demonstrate that the benefits it confers on humankind outweigh their costs - material, social and spiritual.'

Coombs 1985, p.2

S.125

'Since publishing the Logik der Furschung (that is, since 1934) I have developed a more systematic treatment of the problem of scientific method: I have tried to start with some suggestions about the aims of scientific activity, and to derive most of what I have to say about the methods of science - including many comments about its history - from this suggestion ...

To speak of “the aim” of scientific activity may perhaps sound a little naive; for clearly, different scientists have different aims, and science itself (whatever that may mean) has no aims. I admit all this. Yet when we speak of science, we do seem to feel, more or less clearly, that there is
something characteristic of scientific activity; and since scientific activity looks pretty much like a rational activity, and since a rational activity must have some aim, the attempt to describe the aim of science may not be entirely futile.

I suggest that it is the aim of science to find satisfactory explanations of whatever strikes us as being in need of explanation. By an explanation (or a causal explanation) is meant a set of statements one of which describes the state of affairs to be explained (the explicandum) while the others, the explanatory statements, for the "explanation" in the narrower sense of the word (the explicans of the explicandum).'

*Popper 1956, 1983, pp. 131-2*

S.126 'There is a tendency to forget that all science is bound up with human culture in general, and that scientific findings, even those which at the moment appear the most advanced and esoteric and difficult to grasp, are meaningless outside their cultural context. A theoretical science unaware that those of its constructs considered relevant and momentous are destined eventually to be framed in concepts and words that have a grip on the educated community and become part and parcel of the general world picture - a theoretical science, I say, where this is forgotten, and where the initiated continue musing to each other in terms that are, at best, understood by a small group of close fellow travellers, will necessarily be cut off from the rest of cultural mankind [sic]; in the long run it is bound to atrophy and ossify however virulently esoteric chat may continue within its joyfully isolated groups of experts.'

*Schrödinger 1952, quoted by Redner 1987, pp. 201-2*

S.127 'Over the course of human history, people have developed many interconnected and validated ideas about the physical, biological, psychological, and social worlds. These ideas have enabled successive generations to achieve an increasingly comprehensive and reliable understanding of the human species and its environment. The means used to develop these ideas are particular ways of observing, thinking, experimenting, and validating. These ways represent a fundamental aspect of the nature of science and reflect how science tends to differ from other modes of knowing.

It is the union of science, mathematics, and technology that forms the scientific endeavour and that makes it so successful. Although each of these human enterprises has a character and history of its own, each is dependent on and reinforces the others.'

*Science for All Americans, quoted in Project 2061 AAAS 1993, p.3*

S.128 'A scientific world view is not something that working scientists spend a lot of time discussing. They just do science. But underlying their work are several beliefs that are not always held by nonscientists. One is that by working together over time, people can in fact figure out how the world works. Another is that the universe is a unified system and knowledge gained from studying one part of it can often be applied to other parts. Still another is that knowledge is both stable and subject to change.'

*Project 2061 AAAS 1993, p.5*

S.129 'Scientific inquiry is more complex than popular conceptions would have it. It is, for instance, a more subtle and demanding process than the naive idea of "making a great many careful observations and then organising them." It is far more flexible than the rigid sequence of steps commonly depicted in textbooks as "the scientific method". It is much more than just "doing experiments," and it is not confined to laboratories. More imagination and inventiveness are involved in scientific inquiry than many people realise, yet sooner or later strict logic and empirical evidence must have their day. Individual investigators working alone sometimes make great discoveries, but the steady advancement of science depends on the enterprise as a whole. And so on.'

*Project 2061 AAAS 1993, p.9*

S.130 'Scientific activity is one of the main features of the contemporary world and distinguishes present times from earlier periods. As an endeavour for learning how the world works, it provides a living for a very large number of people.'

*Project 2061 AAAS 1993, p.14*

S.131 'By "science," Project 2061 means basic and applied natural and social science, basic and applied mathematics, and engineering and technology, and their interconnections - which is to say the scientific enterprise as a whole. The basic point is that the ideas and practice of science, mathematics, and technology are so closely intertwined that we do not see how education in any one of them can be undertaken well in isolation from the others.'

*Project 2061 AAAS 1993, p.321-2*
Table A.1
A semantic analysis of the summary statements of science given in Fig. A.1, based on Lay's (1982) suggested method for analysing definitions

<table>
<thead>
<tr>
<th>Subject Class:</th>
<th>Differentiae:</th>
<th>Key Words</th>
</tr>
</thead>
</table>
| Science | 1a. is the systematic study | • of man
• and [of] his environment
• based on the deductions and inferences which can be made
• and the general laws which can be formulated
• from reproducible observations and measurements of events and parameters within the universe |
| or, 1a. is the ... study | • [which is] systematic
• of [humanity]
• [of human] environment
• based on the deductions and inferences which can be made,
• and the general laws which can be formulated,
• from reproducible observations and measurements of events and parameters within the universe |
| or, 1b. is the knowledge | • so obtained [from 1a] |
| 2. is ... knowledge | • in general
• systematised |
| 3. is ... knowledge | • a particular branch of |
| 4. is skill; proficiency | |

S.2 The task of science
is to [both] extend the range of experience and [is] to reduce [the range of experience] • to order

This could be reworked to make science the subject, in line with the structure of comparable texts. Thus:

Science
[has as its] task, [to] • extend the range of experience
• reduce (the range of experience)
• to order. | TASK
• extend... experience
• reduce ...[experience]
• order |

S.3 Science
is all exploratory activities • of which the purpose is to come to a better understanding of the natural world

or, science
is ... activities • [which are] exploratory
• of which the purpose is to come to a better understanding of the natural world

ACTIVITIES
• exploratory
• purpose
• come to
• understanding
• natural world
<table>
<thead>
<tr>
<th>S. 4 Science</th>
<th>is a developing body of knowledge</th>
<th>KNOWLEDGE, BODY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• [comprising] observations, concepts, laws and theories</td>
<td>• developing</td>
</tr>
<tr>
<td></td>
<td>• which seeks to explain objectively the world around us</td>
<td>• observations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• concepts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• laws</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• theories</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• seeks to</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• explain</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• world around us</td>
</tr>
</tbody>
</table>

This subject could be read as a body (of knowledge) or as knowledge (which is a body, not disconnected elements).

<table>
<thead>
<tr>
<th>S. 5 The term 'science'</th>
<th>defines a domain of human knowledge and (defines) activity</th>
<th>KNOWLEDGE, ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• within which scientists seek the systematic organisation of knowledge about the composition and functioning of the universe.</td>
<td>• domain</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• human</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• scientists</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• seek</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• systematic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• organisation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• knowledge</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• universe</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>[The work of scientists]</th>
<th>[is to] attempt to acquire knowledge</th>
<th>[about the universe and its parts]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• through the formulation of laws and theories describing natural processes, the interaction and interrelationship of those parts.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• about the universe and its parts</td>
<td></td>
</tr>
</tbody>
</table>

This example introduces two conventions used in this Table.

a. The subject, 'the term "science"', may be taken as simply 'science' for the purpose of this analysis; both the sense and structure of the statement is retained. It has been left, therefore, in its original wording. The subject, 'the work of scientists', may also be replaced with 'science', but for a different reason. In this case, we may say reasonably that the work of scientists is 'science', or 'doing science'. The rest of the sentence tells us what scientists do when they are doing 'science'. However, this requires some rewording of the sentence, which is given below.

b. This example is one of many summary statements which discuss what their authors consider to be key features but which are not worded as definitive statements. We are not in a position, therefore, to infer that no other characteristics are possible in the view of that author, merely that science is at least partly characterised by, or at least entails, the characteristic in question. The wording used hereafter in such examples is to begin with the stem, "Science is or entails ...".
<table>
<thead>
<tr>
<th>Science</th>
<th>[is or entails the] attempt</th>
<th>* to acquire and organise knowledge * about the universe and its parts * and to explain * through the formulation of laws and theories describing natural processes, * the interaction and interrelationship of those parts.</th>
<th>ATTEMPT * acquire * organise * knowledge * the universe and its parts * explain * formulation * laws and theories * describing * natural processes * interaction and interrelationship of those parts.</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Science also entails]</td>
<td>* the goal</td>
<td>* of explaining * with ever increasing precision * the nature of the universe in terms of uniform natural processes and relationships, and</td>
<td>GOAL * explaining * precision * the nature of the universe * uniform natural processes and relationships</td>
</tr>
<tr>
<td></td>
<td>the commitment</td>
<td>* to the testing of proposed explanations * by means of empirical observation and experimentation * [which are] among the characteristics that distinguish science from other fields of human endeavour</td>
<td>COMMITMENT * testing * explanations * empirical observation and experimentation * that distinguish science from other fields of human endeavour</td>
</tr>
<tr>
<td>S.6 Science is the belief</td>
<td>* in the ignorance of experts.</td>
<td>This definition was, quite obviously, not intended as a literal statement but, in the context of the article from which it was taken, had a more figurative meaning. The reworking suggested below is intended to make the figurative or implied meaning more explicit.</td>
<td></td>
</tr>
<tr>
<td>S.7 Science is built up with [related] facts,</td>
<td>* as a house is with stones</td>
<td>BUILT</td>
<td></td>
</tr>
<tr>
<td>[but is not built up with unrelated facts]</td>
<td>* [like] a heap of stones.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S.8 Science is an activity</td>
<td>* [which is] characterised by the search for understanding</td>
<td>ACTIVITY * search * understanding</td>
<td></td>
</tr>
<tr>
<td>[implies an] explanation</td>
<td>* [which is] satisfying * which is concerned with some aspect of reality * is codified in statements * of high generality (laws and principles) * these being accessible to experimental tests.</td>
<td>EXPLANATION * satisfying * reality * codified * [general] statements * experimental tests * laws and principles</td>
<td></td>
</tr>
<tr>
<td>S.9 This is similar to A1.8 above.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

This definition was, quite obviously, not intended as a literal statement but, in the context of the article from which it was taken, had a more figurative meaning. The reworking suggested below is intended to make the figurative or implied meaning more explicit.

This definition is complex in two respects. It contains a definition within a definition (it defines science in terms of a search for understanding, then defines what is meant by understanding. It also provides both explicit and implicit meanings, hence the second analysis of ‘science’ below. The complexity probably arises because of the large number of ideas compressed into a single sentence.

This is similar to A1.8 above.
| Science | is a search | • for understanding  
• expressed in laws or principles of greatest generality  
• which are capable of experimental test  
• [as practised in modern times] | SEARCH  
• for understanding  
• laws or principles  
• greatest generality  
• capable of experimental test  
• modern times |
| --- | --- | --- |
| S.10 Science | is the attempt | • to make the chaotic diversity of our sense experience correspond to a logically uniform system of thought. | ATTEMPT  
• chaotic diversity of our sense experience  
• make ... correspond to  
• system of thought  
• logically  
• uniform |
| S.11 The purpose of science as an activity or, science | is to form conceptual generalisations | • about the many particulars of empirical evidence. | ACTIVITY  
• purpose  
• conceptual generalisations  
• empirical evidence |
| S.12 Science | is a word which describes a way of knowing. | KNOWING, WAY OF |
| S.13 Science | is [an] activity | • [of] human[s]  
• that has evolved as a way of looking at the physical and biological world  
• [that has evolved as] a way of ordering [the] many facets [of this physical and biological world]  
• [that has evolved as] a way of checking the validity of this order. | ACTIVITY  
• human  
• evolved  
• a way of looking  
• the physical and biological world  
• a way of ordering  
• a way of checking  
• validity |
| S.14 'Science' | [is a term which is] usually assumed to [be] very precise and well-defined but [which] can in fact be used in a variety of ways. |  |

The entry immediately above does not address 'science', or the term 'science' as defined, but instead discusses the ways in which the term (the language) is used. It does not, therefore, stand comparison meaningfully with the other definitions included in this table. It remains included in the interests of presenting the several sections of the entry A1.14.
<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>S.15</strong></td>
<td>This statement is worded, 'Science is not just a …', which is taken to mean that science is at least in part, or at least entails, a collection of laws and/or a catalogue of facts.</td>
<td></td>
</tr>
<tr>
<td>Science</td>
<td>is [partly] laws</td>
<td>• a collection of</td>
</tr>
<tr>
<td></td>
<td>is [partly] facts</td>
<td>• a catalogue of</td>
</tr>
</tbody>
</table>
|        | is a creation    | • of the human mind  
|        | [Science]       | • with … freely invented ideas and concepts |
|        | [is partly] physical theories | • which try to form a picture of reality  
|        |                   | • which try to establish … connections [between reality and] the wide world of sense impressions. |
|S.16 | Science | is a world picture  
|      |           | • [and] is not a technique … [or] a form of power … [or] even simply an accumulation of knowledge |
|      |           | is a highly integrated form of knowledge  
|      |           | • which makes a world view. |
|S.17 | Science | is common sense  
<p>|      |           | • at its best |</p>
<table>
<thead>
<tr>
<th>S.18</th>
<th>Science (in the broader sense)</th>
</tr>
</thead>
<tbody>
<tr>
<td>is rigidly accurate</td>
<td>• in observation</td>
</tr>
<tr>
<td>is merciless</td>
<td>• to fallacy in logic.</td>
</tr>
</tbody>
</table>

| [is] any general understanding | • which can respond to challenge and questions | UNDERSTANDING |
| [is] a system | • essentially relating to the development of knowledge |
| | [comprising] the producers (researchers), |
| | the process of research |
| | the products (of research) |
| | the interesses of these products |
| | the reporting subsystem |
| | which itself forms part of a larger system: science in society |
| is industries | [which are] knowledge producing |
| | and knowledge distributing | INDUSTRIES |

| [is essentially an] enterprise | • knowledge producing |
| | knowledge improving | ENTERPRISE |

<table>
<thead>
<tr>
<th>S.20</th>
<th>Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>is an activity</td>
<td>• which takes place in a particular sort of tradition.</td>
</tr>
</tbody>
</table>

Then follows an explanation of what the tradition of science is, which can be taken as further explanation of the term science:

<table>
<thead>
<tr>
<th>S.21</th>
<th>Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>[is or entails] a tradition</td>
<td>• essentially centred in a paradigm, or conceptual structure</td>
</tr>
<tr>
<td></td>
<td>which has a naturalistic metaphysics and an empirical epistemology</td>
</tr>
<tr>
<td>[entails two] goals and objectives</td>
<td>• to predict and control phenomena revealed by the metaphysics and epistemology of the paradigm</td>
</tr>
<tr>
<td></td>
<td>• to explain and understand these same phenomena.</td>
</tr>
</tbody>
</table>

| [is or entails] propositions | [which are] empirical, positive (non normative), operational, falsifiable |
| [in] Anglo-American parlance |

| or ... study | [which is] systematic |
| of natural (non societal, non cultural) phenomena. | STUDY |

The text unit below could be taken either as the class SYSTEMS or as the class KNOWLEDGE, so both are given. The differentiae are set out under the two in order to avoid repeating lists.
<table>
<thead>
<tr>
<th>Science</th>
<th>is a body of ... knowledge</th>
<th>BODY, KNOWLEDGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[which is] coherent, systematic</td>
<td>• body of [knowledge]</td>
</tr>
<tr>
<td></td>
<td>[in] the broadest international consensus</td>
<td>• coherent</td>
</tr>
<tr>
<td></td>
<td>of any subject, formal or empirical, natural or cultural,</td>
<td>• systematic</td>
</tr>
<tr>
<td></td>
<td>arrived at by any method whatever, provided it</td>
<td>• of any subject</td>
</tr>
<tr>
<td></td>
<td>(1) is based on hard, honest and serious study and research and reaches insights not available to laymen or superficial observers, and</td>
<td>• formal or empirical</td>
</tr>
<tr>
<td></td>
<td>(2) is designed for either intellectual or general-pragmatic purposes, but not for immediate practical application in a concrete case or situation.</td>
<td>• natural or cultural</td>
</tr>
<tr>
<td></td>
<td>(1) is based on hard, honest and serious study and research and reaches insights not available to laymen or superficial observers, and</td>
<td>• method</td>
</tr>
<tr>
<td></td>
<td>(2) is designed for either intellectual or general-pragmatic purposes, but not for immediate practical application in a concrete case or situation.</td>
<td>• study and research</td>
</tr>
<tr>
<td></td>
<td>(1) is based on hard, honest and serious study and research and reaches insights not available to laymen or superficial observers, and</td>
<td>• insights</td>
</tr>
<tr>
<td></td>
<td>(2) is designed for either intellectual or general-pragmatic purposes, but not for immediate practical application in a concrete case or situation.</td>
<td>• not available to laymen or superficial observers</td>
</tr>
<tr>
<td></td>
<td>(1) is based on hard, honest and serious study and research and reaches insights not available to laymen or superficial observers, and</td>
<td>• for either intellectual or general-pragmatic purposes</td>
</tr>
<tr>
<td></td>
<td>(2) is designed for either intellectual or general-pragmatic purposes, but not for immediate practical application in a concrete case or situation.</td>
<td>• not for immediate practical application</td>
</tr>
<tr>
<td></td>
<td>(1) is based on hard, honest and serious study and research and reaches insights not available to laymen or superficial observers, and</td>
<td>broadest international consensus</td>
</tr>
<tr>
<td></td>
<td>(2) is designed for either intellectual or general-pragmatic purposes, but not for immediate practical application in a concrete case or situation.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Science</th>
<th>is ... technique</th>
<th>TECHNIQUE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[which is] ordered</td>
<td>ordered</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Science</th>
<th>is ... mythology</th>
<th>MYTHOLOGY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[which is] rationalised</td>
<td>rationalised</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Science</th>
<th>is ... knowledge</th>
<th>KNOWLEDGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a cumulative tradition of</td>
<td>in the contemporary world</td>
</tr>
<tr>
<td></td>
<td>in the contemporary world</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Science</th>
<th>is ... tradition</th>
<th>TRADITION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>of knowledge</td>
<td>knowledge</td>
</tr>
<tr>
<td></td>
<td>cumulative</td>
<td>cumulative</td>
</tr>
<tr>
<td></td>
<td>in the contemporary world</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Science</th>
<th>is ... production</th>
<th>PRODUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>the maintenance and development of</td>
<td>in the contemporary world</td>
</tr>
<tr>
<td></td>
<td>in the contemporary world</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Science</th>
<th>is one of the most powerful influences moulding beliefs and attitudes</th>
<th>BELIEFS AND ATTITUDES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>to the universe and man</td>
<td>to the universe and [humanity]</td>
</tr>
<tr>
<td></td>
<td>in the contemporary world</td>
<td>in the contemporary world</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Science</th>
<th>interacts with society</th>
<th>SOCIETY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[not as] different 'sciences', [but]</td>
<td>multiplicity of aspect</td>
</tr>
<tr>
<td></td>
<td>in the contemporary world</td>
<td>in the contemporary world</td>
</tr>
</tbody>
</table>
| S.25 [Science] | [emphasis] objective features | • [in the] standard view  
  • largely shared by reflective scientists, technical philosophers, and the educated public alike | OBJECTIVE  
  • standard view  
  • shared by reflective scientists, technical philosophers, and the educated public alike |
<table>
<thead>
<tr>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>has ... been widely entrenched</td>
<td>ENTRENCHED</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[has been] taken for granted</td>
<td>TAKEN FOR GRANTED</td>
<td></td>
</tr>
</tbody>
</table>
| | has ... enjoyed the staunch support of ... philosophies | [PHILOSOPHICAL] SUPPORT  
  • of our day  
  • dominant [and] scientifically oriented |
| | [requires] a firm set of ... attitude | ATTITUDES  
  • habitual |
| | [and entails a] moral motivation | MORAL MOTIVATION  
  • underlying  
  • ideal of responsibility  
  • belief  
  • against wilfulness, authoritarianism, and inertia |
| S.26 Science | [is or entails a] method | METHOD  
  • reality  
  • objectivity  
  • method  
  • ontological vision  
  • universe of objects with independent existences and careers |
| | [is or entails] wisdom | WISDOM  
  • standard view  
  • objectivity  
  • end  
  • beginning |
| S.27 [Science] | [is objective] | [OBJECTIVE]  
  • [standard] view |
| S.28 | (Science) | [is or entails an] aim | in the standard view  
| | | | to discover truths  
| | | | about the external world  
| S.29 | This quote is actually worded as 'what science gives us is ...', which is not the same as saying science actually is these things. However, it does match the intentions of the present exercise, namely to collect statements of the sort, 'science is characterised by ...' and will therefore be included in the reworded format to be consistent with the other statements in this analysis. | AIMS | in the standard view  
| | | | discover  
| | | | truths  
| | | | external world  

| Science | [is or entails] criteria of judgement | CRITERIA OF JUDGEMENT  
| | |  
| | | for evaluating data  
| | | METHODS  
| | | for evaluating data  
| | | METHODS  
| | | for logic and rationality  
| | | COMMITMENT  
| | | logic and rationality  
| | [is knowledge] | [that is] human  
| | | [and therefore] value-oriented  
| | | because it is selective. What is relevant to a scientific problem and what has meaning in science depends on what we are looking for and what we are trying to accomplish.  
| | | KNOWLEDGE  
| | | human  
| | | value-oriented  
| | | selective  
| | | what we are looking for and what we are trying to accomplish  
| S.30 | Science | [is methods] | a set of  
| | | | characteristic  
| | | | by means of which knowledge is certified  
| | | | METHODS  
| | | | set  
| | | | characteristic  
| | | | knowledge  
| | | | certified  
| | [is knowledge] | a stock of accumulated  
| | | stemmming from the application of these methods  
| | | KNOWLEDGE  
| | | stock of accumulated  
| | | methods  
| | [is values and mores] | a set of cultural  
| | | governing the activities termed scientific, or  
| | | VALUES AND MORES  
| | | set  
| | | cultural  
| | | governing [scientific] activities  
| | [is any combination of the foregoing] | METHODS, KNOWLEDGE, VALUES IN COMBINATION  
<p>|</p>
<table>
<thead>
<tr>
<th>S.31</th>
<th>Science</th>
<th>[is or entails] the value posture</th>
<th>VALUE POSTURE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>• [which is] rationalistic in the choice of alternatives,</td>
<td>• rationalistic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• relativistic in judgement and expectation, and</td>
<td>• relativistic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• anticipatory of change;</td>
<td>• judgement and expectation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• [where a] pragmatic rationalism may be contrasted with a ritualistic motivation for action;</td>
<td>• anticipates change</td>
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<td></td>
<td></td>
<td>• [which calls] differing value judgements into play in accord with specific roles ...</td>
<td>• pragmatic [rather than ritualistic]</td>
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<tr>
<td></td>
<td></td>
<td>• [which must be supported by more general societal values, as well as the public power, institutional structures, and class systems appropriate for the purpose.</td>
<td>• value</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• judgements</td>
</tr>
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<td></td>
<td>• roles</td>
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<td></td>
<td></td>
<td></td>
<td>• societal</td>
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<td></td>
<td></td>
<td></td>
<td>• values</td>
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<td></td>
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<td>• public power</td>
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<td></td>
<td></td>
<td></td>
<td>• institutional structures</td>
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<td></td>
<td></td>
<td></td>
<td>• class systems</td>
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<td></td>
<td></td>
<td></td>
<td>• purpose</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>S.32</th>
<th>Science</th>
<th>is common knowledge</th>
<th>COMMON KNOWLEDGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>• extended and refined</td>
<td>• extended and refined</td>
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<tr>
<td></td>
<td></td>
<td>• [whose] validity is of the same order as that of ordinary perception, memory, and understanding</td>
<td>• validity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• [whose] test is found, like theirs, in actual intuition, which sometimes consists in perception and sometimes in intent</td>
<td>• of the same order as that of ordinary perception</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• memory</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• understanding</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• sometimes</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>• intuition</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• intent</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>S.33</th>
<th>Science</th>
<th>is ... a community of individuals</th>
<th>COMMUNITY OF INDIVIDUALS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>• engaged in similar and related activities of inquiry ...</td>
<td>• similar and related</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• [which] must necessarily have a philosophy, just like any other group of people asking questions ...</td>
<td>• activities of inquiry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• [whose] disagreements are philosophical conflicts - conflicts, among other things, in regard to ultimate kinds of explanatory ideas ...</td>
<td>• must ... have a philosophy</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• like any other group of people</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• asking questions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• disagreements are philosophical conflicts</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• ultimate kinds of explanatory ideas</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>S.34</th>
<th>Science</th>
<th>is ... [a] process</th>
<th>PROCESS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>[that is] active</td>
<td>• active</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• that can be followed through the ages</td>
<td>• through the ages</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• [that is] valid and successful in our own age</td>
<td>• valid and successful</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• [which] has given rise to a good deal of misunderstanding of its nature and not a little misapplication of such terms as 'science' and 'scientific' ...</td>
<td>• in our own age</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• great progressive</td>
<td>• misunderstanding of its nature</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• of knowledge</td>
<td>• misapplication</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• no static body of knowledge</td>
<td>• terms</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>S.35</th>
<th>Science</th>
<th>[is or entails] activity</th>
<th>ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>• [of which an element is its] goals</td>
<td>• goals</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• which set it apart from other human activities</td>
<td>• which set [science] apart from other human activities</td>
</tr>
</tbody>
</table>
| [Science] | **is or entails** goals | • prediction and control  
• [some] seek ... to discover correlations  
• explanation and understanding  
• [which] are not absolutes of all sciences  
• prediction and control involve statements which use only correlations, whereas explanation and understanding involve statements which use causal connections. |
|---|---|---|
|   | **GOALS** | • prediction and control  
• seek ... to discover correlations  
• explanation and understanding  
• not absolutes of all sciences  
• prediction and control involve statements which use only correlations, whereas explanation and understanding involve statements which use causal connections. |

### S.36 Science

| **Science** | **is an ... activity,** | • [which is] open-ended  
• on-going  
• [whose] character has changed significantly during its history |
|---|---|---|
|   | **ACTIVITY** | • open-ended  
• on-going  
• [changing] character  
• history |

| **Science** | **is ... [an] enterprise** | • [that is] not ... monolithic  
• can lead to false theories |
|---|---|---|
|   | **ENTERPRISE** | • not monolithic  
• can lead to  
• false  
• theories |

<table>
<thead>
<tr>
<th><strong>Science</strong></th>
<th><strong>is or entails</strong> roots</th>
<th>• in everyday circumstances, needs, methods, concepts, etc. of human beings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>ROOTS</strong></td>
<td>• in everyday circumstances, needs, methods, concepts, etc. of human beings</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Science</strong></th>
<th><strong>is or entails</strong> ... notions</th>
<th>• [such] as 'observation', 'theory', 'meaning', 'reference', 'explanation', 'progress' and 'rationality'</th>
</tr>
</thead>
</table>
|   | **NOTIONS** | • observation  
• theory  
• meaning  
• reference  
• explanation  
• progress  
• rationality |

<table>
<thead>
<tr>
<th><strong>Science</strong></th>
<th><strong>[is often not clearly distinguishable from philosophy],</strong></th>
<th>• especially as regards foundational problems</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>[NOT CLEARLY DISTINGUISHABLE FROM PHILOSOPHY]</strong></td>
<td>• foundational problems</td>
</tr>
</tbody>
</table>

### S.37 Science

<table>
<thead>
<tr>
<th><strong>Science</strong></th>
<th><strong>[is or entails] knowledge</strong></th>
<th>• [often characterised more by] its arrangement [than by its] subject matter</th>
</tr>
</thead>
</table>
|   | **KNOWLEDGE** | • arrangement  
• subject matter |

<table>
<thead>
<tr>
<th><strong>Science</strong></th>
<th><strong>[is or entails] knowledge</strong></th>
<th>• that is sufficiently organised to exhibit appropriate evidential relationships among its constituent claims</th>
</tr>
</thead>
</table>
|   | **KNOWLEDGE** | • organised  
• appropriate  
• evidential  
• relationships  
• constituent claims |

<table>
<thead>
<tr>
<th><strong>Science</strong></th>
<th><strong>is [or entails] system</strong></th>
<th>• whatever the subject and what makes for system is the judicious application of logic</th>
</tr>
</thead>
</table>
|   | **SYSTEM** | • subject  
• judicious  
• application of logic |

<table>
<thead>
<tr>
<th><strong>Science</strong></th>
<th><strong>is ... a fruit of ... investigation</strong></th>
<th>• rational</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>FRUIT OF INVESTIGATION</strong></td>
<td>• rational</td>
</tr>
</tbody>
</table>

### S.38 Science

<table>
<thead>
<tr>
<th><strong>Science</strong></th>
<th><strong>[is or entails] the methods</strong></th>
<th>• by which we acquire knowledge of nature, and ... set that knowledge within a more comprehensive metaphysics.</th>
</tr>
</thead>
</table>
|   | **METHODS** | • acquire  
• knowledge  
• of nature  
• set ... within a more comprehensive metaphysics |

| **Science** | | |
| S.39 Science | is ... activity | • [that is] very complex  
• different ideals of scientific reasoning  
• steps of reasoning by which laws of nature are formulated on the basis of factual evidence, and  
• by which the effect of new evidence on our confidence in the truth of laws is assessed. | ACTIVITY  
• complex  
• ideals of scientific reasoning  
• steps of reasoning  
• laws  
• of nature  
• formulated  
• evidence  
• confidence in the truth of laws  
• assessed |
|---|---|---|
| S.40 Science | is ... theories | • collection  
• well-attested  
• which explain the patterns and regularities and irregularities among carefully studied phenomena. | THEORIES  
• collection  
• well-attested  
• explain  
• patterns and irregularities  
• carefully  
• studied  
• phenomena |
| S.41 Science | [is or entails] research | • conducted toward the finding and the testing of highly testable hypotheses [on Popper's account]  
• very often conducted toward the finding and the testing of metaphysically relevant hypotheses [on Agassi's account]  
• [which] tends to begin with hypotheses which have a low degree of testability or are not testable at all. | RESEARCH  
• conducted toward  
• finding and ... testing  
• highly testable  
• hypotheses  
• metaphysically relevant |
| S.42 Science | [is] empirical ... i.e., refutable | [which it] manifests ... more systematically than mathematics. | EMPIRICAL (REFUTABLE)  
• which are lacking in mathematics |
| | [is or entails] other characteristics  
i.e., [is or entails] informative content, explanatory power, simplicity, abstractness, generality, and precision | OTHER CHARACTERISTICS  
• lacking in mathematics  
INFORMATIVE CONTENT  
EXPLANATORY POWER  
SIMPLICITY  
ABSTRACTNESS  
GENERALITY  
PRECISION |
| S.43 Science | [is or entails the] aim | • to comprehend the world rationally  
• as we all agree (including the positivists who should disagree)  
• [where] rationality [according to Popper] is manifest in empirical tests | AIM  
• comprehend  
• the world  
• rationally  
• as we all agree  
• rationality  
• empirical tests |
| S.44 Science | [is or entails] the ... clarification of problems | • progressive  
• [as shown in the history of science] | CLARIFICATION OF PROBLEMS  
• progressive  
• history of science |
| [is or entails the asking of] questions | ...about nature  
...instead of waiting to see what turns up; and  
[which are] intrinsically answerable questions, as distinct from nonsensical questions | ASKING OF QUESTIONS  
...about nature  
...instead of waiting to see  
answerable questions |
|---|---|---|
| S.45 Science | [is] ontology [and] the sciences are regional ontologies | [for which] every substantive scientific problem is ... What is the world like?  
ONTOGONY  
...[what ... the world is like] |
| S.46 Science | [is or entails study] | of systems  
...whether natural ... or artificial |
| S.47 Science | [is or entails the belief, or regards] | the natural world ... as real and objective  
[whose] characteristics cannot be determined by the preferences or intentions of its observers  
[but can be] more or less faithfully represented  
in the standard view  
BELIEF  
...natural world  
...real and objective  
preferences or intentions of ...  
observers  
...more or less faithfully  
represented  
standard view |
| | is that intellectual enterprise | concerned with providing an accurate account of the objects, processes and relationships occurring in the world of natural phenomena  
INTELLECTUAL ENTERPRISE  
...accurate account  
...natural phenomena |
| | [is or entails] knowledge | in ... systematic statements  
reveals ... the true character of this world  
[that] has satisfied ... impersonal, technical criteria of adequacy  
is independent of ... subjective factors  
KNOWLEDGE  
...imperonal  
...technical  
...[not] subjective |
| | [is or entails] criteria | [that are] stringent  
in connection with experimental procedures  
by means of which empirical knowledge claims are evaluated and their accurate representation of empirical phenomena is ensured  
CRITERIA  
...stringent  
experimental procedures  
knowledge claims  
evaluated  
accurate  
representation  
empirical phenomena  
ensured |
| S.48 ...Pure or basic science | [is] ... research | [that is] somewhat ephemeral  
whose most immediate goal is to increase understanding rather than control of nature  
[which] characteristic problems are almost always repetitions, with minor modifications, of problems that have been undertaken and partially resolved before  
RESEARCH  
...somewhat ephemeral  
immediate goal  
understanding  
nature  
problems  
repetitions ... of problems |
<table>
<thead>
<tr>
<th>Page</th>
<th>Section</th>
<th>Description</th>
<th>Knowledge</th>
<th>Activities</th>
<th>Statements (Analytic)</th>
<th>Statements (Synthetic)</th>
<th>Methodology</th>
<th>Research</th>
<th>Knowledge</th>
<th>Mathematics</th>
<th>Culture</th>
<th>Processes of the Natural World</th>
<th>Laws</th>
<th>Mathematical Formulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>S.49</td>
<td>Science in its widest sense</td>
<td>[is] theoretical knowledge</td>
<td>* no matter whether in the field of natural sciences or in the field of the social sciences and the so-called humanities, and</td>
<td>KNOWLEDGE</td>
<td>theoretical</td>
<td>in the field of natural sciences</td>
<td>in the field of the social sciences</td>
<td>scientific procedures</td>
<td>common sense</td>
<td>based on everyday life</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>* no matter whether it is knowledge found by the application of special scientific procedures, or knowledge based on common sense in everyday life</td>
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<tr>
<td></td>
<td></td>
<td>[is] activities</td>
<td>* which we carry out in everyday life in order to know something</td>
<td>ACTIVITIES</td>
<td>in everyday life</td>
<td>in order to know</td>
<td>systematic</td>
<td></td>
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<td></td>
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<td></td>
<td>* [but] a more systematic continuation of those activities</td>
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<td></td>
<td>Formal science</td>
<td>[is or entails] analytic statements</td>
<td>* established by logic and mathematics</td>
<td>STATEMENTS (ANALYTIC)</td>
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<tr>
<td></td>
<td>Empirical science</td>
<td>[is or entails] synthetic statements</td>
<td>* established in the different fields of factual knowledge</td>
<td>STATEMENTS (SYNTHETIC)</td>
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<tr>
<td>S.50</td>
<td>Science</td>
<td>[is or entails] knowledge</td>
<td>* [which] is experimental knowledge</td>
<td>KNOWLEDGE</td>
<td>experimental</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>[is or entails] research</td>
<td>* [in which characteristically] observational evidence plays a crucial role in the resolution of the issue between contending hypotheses</td>
<td>RESEARCH</td>
<td>observational evidence</td>
<td>resolution</td>
<td>between contending hypotheses</td>
<td>objectivity</td>
<td>scientific method</td>
<td></td>
<td></td>
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<td>* [and on which the] objectivity [of] scientific method depends</td>
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<td></td>
<td></td>
<td>[is or entails] methodology</td>
<td>* [which is remarkable for and is characterised by its] resolution of disputed issues and establishment of instrumental knowledge and [and is] strongly dependent upon the special role it assigns to observation.</td>
<td>METHODOLOGY</td>
<td>resolution of disputed issues</td>
<td>establishment</td>
<td>instrumental knowledge</td>
<td>observation</td>
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<tr>
<td>S.51</td>
<td>Science</td>
<td>[is] that ... culture</td>
<td>* [which is] peculiar</td>
<td>CULTURE</td>
<td>peculiar</td>
<td>the hallmark of Western civilisation</td>
<td>discovery or uncovering</td>
<td>of nature</td>
<td>central focus</td>
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<td>* which is the hallmark of Western civilisation</td>
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<td>* makes the discovery or uncovering of nature its central focus</td>
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<tr>
<td>S.52</td>
<td>Science</td>
<td>is the ... mathematical formulation</td>
<td>* exact</td>
<td>MATHEMATICAL FORMULATION</td>
<td>exact</td>
<td>processes of the natural world</td>
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<td>* of the processes of the natural world</td>
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<tr>
<td></td>
<td></td>
<td>[is] composed of laws</td>
<td>* stating the mathematical behaviour of nature solely</td>
<td>LAWS</td>
<td>mathematical</td>
<td>behaviour of nature</td>
<td>deducible from phenomena</td>
<td>verifiable in phenomena</td>
<td>for Newton</td>
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<td></td>
<td></td>
<td>* clearly deducible from phenomena</td>
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<td></td>
<td>* exactly verifiable in phenomena</td>
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<td>* for Newton</td>
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<tr>
<td>[is] a body of ... truth</td>
<td>[which is] absolutely certain • about the doings of the physical world</td>
<td>BODY OF TRUTH • certain • physical world</td>
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<tr>
<td>[is or entails] methods</td>
<td>• union of mathematical and experimental • ideal exactitude • constant empirical reference • [for] Newton</td>
<td>METHODS • union of mathematical and experimental • ideal exactitude • constant empirical reference • [for] Newton</td>
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</tbody>
</table>

**S.53 Science**

| [is or entails] practice | • [with] ethical principles • conviction that there exists objective truth • there exist rules of evidence for discovering it • on the basis of this objective truth, unanimity is possible and desirable • unanimity must be achieved by independent arrivals at convictions - that is, by examination of evidence, not through coercion, personal argument or appeal to authority | PRACTICE • ethical principles • conviction • objective truth • rules of evidence • discovering • unanimity is possible and desirable • examination of evidence • not through coercion, personal argument or appeal to authority |

| [is a] system of thought | • [which] like all other systems of thought seeks answers to questions which men hold to be of importance • seeks answers which are reducible to everyone’s experience [unlike other systems of thought where] answers are accepted that harmonise with particular world-views peculiar to different cultural complexes | SYSTEM OF THOUGHT • like all other systems … • seeks answers • questions which men hold to be of importance • seeks answers • which are reducible to everyone’s experience • [not] answers [that] are accepted that harmonise with particular world-views peculiar to different cultural complexes |

**S.54 Science**

<table>
<thead>
<tr>
<th>[is or entails] a body of knowledge, and ... a set of rules</th>
<th>• by which this knowledge is to be collected</th>
<th>RULES • set of • [for collection of] knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>[is or entails] a … consensus of opinion</td>
<td>• [which is] fairly widespread • as to what science really is</td>
<td>CONSENSUS OF OPINION • fairly widespread • what science really is</td>
</tr>
<tr>
<td>S.55 Science</td>
<td>is a ... profession</td>
<td></td>
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<td>--------------</td>
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</tr>
<tr>
<td></td>
<td>[according to] Galbraith</td>
<td></td>
</tr>
<tr>
<td></td>
<td>the outmoded image of science still held by many people</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[no longer] 'the product of the individual efforts of men of genius'</td>
<td></td>
</tr>
<tr>
<td></td>
<td>the nineteenth century</td>
<td></td>
</tr>
<tr>
<td></td>
<td>modern science</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[which is] a highly organised new profession closely linked with industry and government</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[whose] success has been achieved by 'taking ordinary men', informing them narrowly and deeply and then, through appropriate organisation, arranging to have their knowledge combined with that of other specialised but equally ordinary men.'</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>S.56 Science</th>
<th>[is] ... linked with politics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>inextricably</td>
</tr>
<tr>
<td></td>
<td>while yet remaining unanswerable to those whose lives are affected by its actions</td>
</tr>
</tbody>
</table>

| KNOWLEDGE | • of the real world |
|           | • observation |
|           | • critically examined |
|           | • classified |
|           | • systematically under general principles |
|           | • explanation |
|           | • of what is of value |
|           | • in past discoveries |
|           | • prediction |
|           | • of future events |
|           | • scientific research (new discovery) |
|           | • concepts |
|           | • a sense of understanding |
|           | • causes of events in the world |
|           | • communicate |
|           | • to others |
|           | • be universal in the sense of independent of space and time |
|           | • explicitly |
|           | • intelligible to all qualified practitioners |
|           | • empirical relevance |
|           | • such that all can evaluate the correspondence |
|           | • theories |
|           | • practical implications |

| PROFESSION | • [according to] Galbraith |
|            | the outmoded image of science still held by many people |
|            | product |
|            | the individual efforts of men of genius |
|            | the nineteenth century |
|            | modern science |
|            | highly organised |
|            | new |
|            | profession |
|            | closely linked with industry and government |
|            | ordinary men |
|            | informing them narrowly and deeply |
|            | appropriate organisation |
|            | arranging |
|            | knowledge |
|            | combined |
|            | other specialised but equally ordinary men |

| LINKED WITH POLITICS | • inextricably |
|                      | yet remaining unanswerable to those whose lives are affected by its actions |
### Science

S.57

| is ... an activity | • [or] a biological phenomenon
|                   | by one kind of organism
|                   | which facilitates its interaction with the environment ...
|                   | [in which on van Fraassen’s account] only the successful theories survive - the ones which in fact latched onto actual regularities in nature
|                   | [but in which on Riggs’ account] the level of empirical adequacy [while] of major importance ... is not the sole consideration

**ACTIVITY**

- biological
- phenomenon
- by one kind of organism
- interaction
- with the environment
- latched onto
- regularities in nature
- empirical adequacy ... not the sole consideration

---

S.58

This entry does not begin with the usual, ‘science is ...’, or similar, but does discuss science as research. The significance of ‘science is characterised as’ compared to ‘science is characterised by’ is addressed in the analysis of this table in Chapter 4. The notion of science as research seems to imply the notion of science as goal-directed activity.

| is or entails research | • [which, on Laudan’s account, has] cognitive goals [concerned with] certain interesting epistemic and pragmatic attributes (and which typically include):
|                       | to acquire *predictive control* over ... parts of one’s experience of the world
|                       | to acquire *manipulative control* over portions of one’s experience so as to be able to intervene in the usual order of events so as to modify that order
|                       | to increase the *precision* of the parameters which feature as initial and boundary conditions in our explanations of natural phenomena
|                       | to integrate and simplify the various components of our picture of the world, reducing where possible to a common set of explanatory principles

**RESEARCH**

- cognitive
- goals
- epistemic
- pragmatic
- to acquire *predictive control*
- over ... parts of one’s experience
- to acquire *manipulative control*
- so as to be able to intervene
- the usual order of events
- modify that order
- to increase the *precision* of the parameters
- initial and boundary conditions
- explanations
- of natural phenomena
- to integrate and simplify
- various components of our picture of the world
- common set
- explanatory
- principles

---

| is or entails] various methods | • of theory testing and of theory selection employed
|                                | ... which ... [over time] produce ... theories over time [that] are
|                                | reliable
|                                | efficient at advancing our cognitive aims and, in general,
|                                | they do so better than theories we denote as 'non-scientific'

**METHODS**

- theory testing and ... selection
- theories
- reliable
- efficient
- cognitive
- aims
- better than ... ‘non-scientific’

---

S.59

| is a ... sub-culture | • [which is] problem-solving
|                     | whose main value is truth

**SUB-CULTURE**

- problem-solving
- main value is truth
### Developing Statements

| is concerned with developing ... statements | [is or entails] testable statements about the world which in turn create images of the world which correspond to what the world is really like | DEVELOPING STATEMENTS
| [is or entails] problem-solving | [is or entails] the main preoccupation of scientists and indeed of the professionals in general | PROBLEM-SOLVING

| S.60 (Physical) science | [is or entails the] aim to establish highly general laws and theories applicable to the world which are tested by pitching them against the world in the most demanding way possible given the existing practical techniques | AIM
| | | • establish highly general laws and theories applicable to the world
| | | • to the world by pitching them against the world
| | | • the most demanding way possible given the existing practical techniques
| | | • generality and degree of applicability of laws and theories is subject to continual improvement

| S.61 Natural science | [is or entails] a vision explored and controlled by argument initiated by ancient Greek philosophers, mathematicians and physicians search for principles at once of nature and of argument itself that is specific created within Western culture, at once of knowledge and of the object of that knowledge, at once of natural science and of nature | VISION
| | | • Western culture
| | | • knowledge of (knowledge) and of the object of that knowledge
| | | • of natural science and of nature

| [is or entails] commitment | [is or entails] the Greeks to the decision of questions by argument and evidence as distinct from custom, edict, revelation, authority or whatever else to make this explicit by analysis of the reasoning involved developing thereby the conceptions of a problem as distinct from a doctrine | COMMITMENT
| | | • to the decision of questions by argument and evidence explicit by analysis of the reasoning conceptions of a problem as distinct from a doctrine

The subject of the text unit below is entered as 'decision', being the literal rewording of the term 'deciding that' in the text unit. However, its use here appears ambiguous. It seems reasonable to interpret its meaning literally, as a conscious decision, and more figuratively, as a belief. Crombie uses the wording 'the commitment of the Greeks for whatever reason' earlier in the passage, apparently for the same intended meaning. Rather ambiguously, Crombie then uses the term 'decision' in a different sense, and for this reason some qualification is necessary to make the class clear. 'Belief' would seem to be interchangeable. However, the class is entered as DECISION because it is in the original.
| Science | [is or entails the decision] | • [that] the one existing world was a world of exclusively self-consistent and discoverable rational causality | • one existing world
• a world of exclusively self-consistent and discoverable rational causality
• effective direction of thinking
• closed to them visions of things still open elsewhere
• conception of nature
• formal reasoning
• matched natural causation
• natural events
• reasoned conclusions
• true principles |
| --- | --- | --- | --- |
| Science | [is characterised by] two fundamental conceptions …: | • causal demonstration and formal proof
• [to the extent it embodies] all Western rational thinking | FUNDAMENTAL CONCEPTIONS
• causal
• demonstration
• formal proof
• Western
• rational
• thinking |
| S.62 Science | [is or entails dealing] only with the world of appearance | • whereas philosophy dealt with the world of something called reality
• on Kant's account | DEALING ONLY WITH THE WORLD OF APPEARANCE
• whereas philosophy dealt with the world of something called reality
• on Kant's account |
| S.63 Science | [is or entails] procedures | • [which have been] amended [by philosophy] | PROCEDURES
• amended
• [by philosophy] |
| S.63 Science | [is or entails] certain rules | • [which have] determined the kind of scientific conclusions that would be acceptable
• based on some metaphysical dogma … that is usually unexamined … because it had been part and parcel of collective thinking and seems self evident | RULES
• [which] scientific conclusions that would be acceptable
• based on some metaphysical dogma
• usually unexamined
• part … of collective thinking
• seems self evident |
| S.64 Science | [is or entails] the scientific mind | • [the mainsprings of which are] curiosity and the desire to generalise … originality and intelligence and perseverance … and the finding of pleasure in the use of the hands in delicate manipulations | SCIENTIFIC MIND
• curiosity
• desire to generalise
• originality
• intelligence
• perseverance
• the finding of pleasure in the use of the hands
• delicate manipulations |
<table>
<thead>
<tr>
<th>S. 65</th>
<th>Natural science</th>
</tr>
</thead>
</table>
| **[aims] to acquire as complete a knowledge as possible** | • of the material universe;  
• of the objects, materials and phenomena and  
• the relations between the phenomena which make themselves known to us or which we apprehend by means of our senses |

<table>
<thead>
<tr>
<th>or, science</th>
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</thead>
<tbody>
<tr>
<td><strong>[is or entails the] aim</strong></td>
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</tbody>
</table>

| **AIM** | • acquire  
• knowledge  
• of the material universe  
• of the objects, materials and phenomena  
• [and of] the relations between the phenomena which make themselves known to us or which we apprehend by means of our senses |

| **STRUCTURE** | • of knowledge  
• approved  
• by all sane men  
• only the sane men who have studied it  
• give their approval |

| **BODY** | • of valid ideas  
• approval  
• an understatement  
• feelings |

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<tr>
<th><strong>S. 66 Science</strong></th>
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<tbody>
<tr>
<td><strong>is not a mere repetition of facts;</strong></td>
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</table>

The difficulty with transposing statements which characterise science in terms of what they are not, as in the example above, is noted. This statement is interpreted to mean that indeed facts are part of the definition or characterisation of science, but not facts alone or in themselves.

<table>
<thead>
<tr>
<th>or, Science</th>
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</thead>
</table>
| **[is or entails facts]** | • [but] not a mere repetition of facts  
• not a mere repetition of facts |

| **FACTS** | • not a mere repetition of facts |

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<tr>
<th><strong>S. 67 Science</strong></th>
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<tbody>
<tr>
<td><strong>[is] the system of behaviour</strong></td>
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</table>

| **SYSTEM, BEHAVIOUR** | • acquires mastery  
• of the environment  
• [on Crowther's account] |

| **USES** | • to serve as an end in itself  
• to form a basis for technology |

Although Baker employed the term *uses*, the meaning in the context of the sentence could be interpreted as *goals*. *Uses* has been designated as the class, above, following the procedure of analysis applied to all summary statements in this table. However, its ambiguous meaning above is noted for consideration later in the analysis.
<table>
<thead>
<tr>
<th><strong>S.68</strong></th>
<th><strong>[is or entails] basic research</strong></th>
<th><strong>BASIC RESEARCH</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Science</td>
<td>• [which] is aimed</td>
<td>• aimed</td>
</tr>
<tr>
<td></td>
<td>• at broadening the base of our</td>
<td>• broadening the base</td>
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<tr>
<td></td>
<td>knowledge of the natural</td>
<td>• knowledge</td>
</tr>
<tr>
<td></td>
<td>world and of how we can use it</td>
<td>• of the natural world</td>
</tr>
<tr>
<td></td>
<td>• both for the sake of advancing</td>
<td>• of how we can use [knowledge]</td>
</tr>
<tr>
<td></td>
<td>that knowledge and</td>
<td>• for the sake of advancing that</td>
</tr>
<tr>
<td></td>
<td>• to provide the background for</td>
<td>knowledge</td>
</tr>
<tr>
<td></td>
<td>the solution of recognised</td>
<td>• to provide the background for</td>
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<td></td>
<td>current or future practical</td>
<td>the solution of</td>
</tr>
<tr>
<td></td>
<td>problems</td>
<td>recognised current or future</td>
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<td></td>
<td></td>
<td>practical problems</td>
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</tbody>
</table>

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<thead>
<tr>
<th><strong>S.69</strong></th>
<th><strong>[is or entails] research</strong></th>
<th><strong>RESEARCH</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>[Science]</td>
<td>• [which can be] basic</td>
<td>• basic</td>
</tr>
<tr>
<td></td>
<td>• [which entails] the advancement of knowledge</td>
<td>• advancement</td>
</tr>
<tr>
<td></td>
<td>• without the goals of long term economic or social benefits</td>
<td>• of knowledge</td>
</tr>
<tr>
<td></td>
<td>• no positive efforts ... made to apply the results to practical problems</td>
<td>• without the goals</td>
</tr>
<tr>
<td></td>
<td>• [or which can be] strategic</td>
<td>• long term economic or social benefits</td>
</tr>
<tr>
<td></td>
<td>• [to] produce a broad base of knowledge [for] the solution of recognised current or future practical problems</td>
<td>• practical problems</td>
</tr>
<tr>
<td></td>
<td>• long standing separation of scientific and industrial research in Australia</td>
<td>• strategic</td>
</tr>
<tr>
<td></td>
<td>• [with] research objectives either as advancing knowledge or as contributing to the immediate solution of an industrial problem</td>
<td>• expectation</td>
</tr>
<tr>
<td></td>
<td>• occasional examples of discovery, development or application</td>
<td>• to produce a broad base of knowledge</td>
</tr>
<tr>
<td></td>
<td>• discovery more often contributes to an international matrix of information and understanding</td>
<td>• [for] the solution of</td>
</tr>
<tr>
<td></td>
<td>• can result in a greater or lesser rearrangement of the whole matrix</td>
<td>• recognised current or future practical problems</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>S.69</strong></th>
<th><strong>[is or entails a] knowledge base</strong></th>
<th><strong>KNOWLEDGE BASE</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• [which is] international</td>
<td>• international</td>
</tr>
<tr>
<td></td>
<td>used to solve problems in a particular application</td>
<td>• used to solve problems</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• in a particular application</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>S.70</strong></th>
<th><strong>The natural sciences and engineering</strong></th>
<th><strong>FIELDS OF SCIENCE</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>are defined as the major fields of science</strong></td>
<td><strong>physical, chemical, biological, earth, engineering and applied, and agriculture</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>excluding the social sciences and humanities</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>(which are concerned with the extension of knowledge about man, culture and society)</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>[not] concerned with ... man, culture and society</strong></td>
</tr>
</tbody>
</table>
| S. 7.1  | [is or entails] research | [which] should be left [to scientists] to do it
|         |                         | [or left to] research managers
|         |                         | [because taxpayer] investment should show some return which will tangibly benefit the country
|         |                         | [and requires] sustained funding, (which requires in turn)
|         |                         | trust on the part of research managers
|         |                         | researchers … to change their view of the aims of their research
|         |                         | [researchers to] have a well developed international reputation
|         |                         | the reasons for following a particular line of research [to] be related to reasons outside of their narrow discipline (in Australia, 1989) [which include]
|         |                         | the ripeness of the area for exploration;
|         |                         | the significance of the questions addressed;
|         |                         | the potential for discovery of fundamental new laws;
|         |                         | the potential for discovery of generalisations of broad scientific applicability;
|         |                         | the attractiveness of the area to the most able scientists;
|         |                         | the potential stimulation of other sciences;
|         |                         | the potential contribution to engineering, medicine, applied science; technology; the goals of society; prestige and international cooperation; national responsibilities; public education;
|         |                         | the potential for immediate applications.
| S. 7.2  | [is or entails a] structure | [which] developed only in Western Europe at the time of Galileo in the late Renaissance
|         |                         | [which has] the fundamental bases … the application of mathematical hypotheses to Nature,
|         |                         | the full understanding and use of the experimental method,
|         |                         | the distinction between primary and secondary qualities,
|         |                         | the geometricalization of space,
|         |                         | the acceptance of the mechanical model of reality.
|         |                         | [Western Europe at the time of Galileo in the late Renaissance]
|         |                         | the application of
|         |                         | mathematical hypotheses
|         |                         | to Nature
|         |                         | understanding
|         |                         | use of the experimental method
|         |                         | primary and secondary qualities
|         |                         | geometricalization
|         |                         | of space
|         |                         | acceptance
|         |                         | of the mechanical model of reality
<table>
<thead>
<tr>
<th>Science</th>
<th>S.73</th>
<th>Behaviour</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Science</strong></td>
<td>is ... behaviour</td>
<td>[which is] species-specific, human</td>
</tr>
<tr>
<td><strong>HYPOTHESES</strong></td>
<td>• [modern type]</td>
<td>• species-specific, human</td>
</tr>
<tr>
<td></td>
<td>• the modern type [being distinguished clearly from] the primitive or medieval type</td>
<td>• making plans</td>
</tr>
<tr>
<td></td>
<td>• [whose] intrinsic and essential [precision] ... made them [capable] of proof or disproof, and [not] prone to combine in fanciful systems of gnostic correlation [in contrast to mediaeval hypotheses]</td>
<td>• [not] independent, value-free, dissociated activity which can be carried on apart from the rest of human life</td>
</tr>
<tr>
<td></td>
<td>• [and in which numbers were] employed as the stuff of qualitative measurements compared <em>a posteriori</em> [not] manipulated in forms of &quot;numerology&quot; or number mysticism constructed <em>a priori</em></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strategies</th>
<th>[is or entails] strategies</th>
<th>[for] guiding our long-term attack on how to live and how to look at the world</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STRATEGIES</strong></td>
<td>• [for] guiding</td>
<td>• [for] guiding</td>
</tr>
<tr>
<td></td>
<td>• long-term</td>
<td>• long-term</td>
</tr>
<tr>
<td></td>
<td>• attack on how to live and how to look</td>
<td>• attack on how to live and how to look</td>
</tr>
<tr>
<td></td>
<td>• at the world</td>
<td>• at the world</td>
</tr>
<tr>
<td></td>
<td>• no distinction [from] human strategies</td>
<td>• no distinction [from] human strategies</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>World View</th>
<th>is a world view</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WORLD-VIEW</strong></td>
<td>based on the notion that we can plan by understanding</td>
</tr>
<tr>
<td></td>
<td>• distinguished from magical views by the fact that it refuses to acknowledge a division between two kinds of logic</td>
</tr>
<tr>
<td></td>
<td>• [whose logic] works the same way in all forms of conduct and is not carried out by any kind of formula but by an active view of how you apply the logic of long-term planning strategies to the conduct of the whole of your life</td>
</tr>
<tr>
<td></td>
<td>• distinguished from earlier forms of trying to achieve a unitary view of the world by the fact that there is only one form of truth in it. There is no distinction between man and nature, there is no distinction between the logic of magic and other logics, and there is no distinction between means and ends</td>
</tr>
<tr>
<td></td>
<td>• based on the notion</td>
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<td></td>
<td>• we can plan</td>
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<td></td>
<td>• understanding</td>
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<td></td>
<td>• distinguished from magical views</td>
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<td></td>
<td>• refuses to acknowledge a division between two kinds of logic</td>
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<td></td>
<td>• same way in all forms of conduct</td>
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<td></td>
<td>• not ... by ... formula</td>
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<td></td>
<td>• active view of how</td>
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<tr>
<td></td>
<td>• apply the logic</td>
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<td></td>
<td>• long-term</td>
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<td></td>
<td>• planning strategies</td>
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<td></td>
<td>• to the conduct of the whole of your life</td>
</tr>
<tr>
<td></td>
<td>• distinguished from earlier forms</td>
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<td></td>
<td>• trying to achieve a unitary view</td>
</tr>
<tr>
<td></td>
<td>• of the world</td>
</tr>
<tr>
<td></td>
<td>• one form of truth</td>
</tr>
<tr>
<td></td>
<td>• no distinction between man and nature</td>
</tr>
<tr>
<td></td>
<td>• no distinction between the logic of magic and other logics</td>
</tr>
<tr>
<td></td>
<td>• no distinction between means and ends</td>
</tr>
</tbody>
</table>
| S.74  | Science | [is] a world picture | WORLD PICTURE | • [not] an isolated or independent activity  
• [which] has the characteristic of being active  
• [which] thinks of knowledge as being directed toward planned action  
• [which rests on] the human species-specific concept … that human beings are planners, that they guide their conduct by looking ahead and making choices |
| S.75  | Science | [is or entails planning] | [PLANNING] | • general human approach  
• guide their conduct by looking ahead and making choices |
|       |        | is an integrated approach | INTEGRATED APPROACH | • cannot … make any bifurcation and say this part of life is scientific and specialised and that is not; nature belongs here, man belongs there; or means belong here but ends stand above all that over there |
|       |        | [is not] magical | [NOT] MAGICAL | • [because in science] you cannot between power and knowledge [but magic does] |
| S.76  | Science | is [or entails] … a belief system | BELIEF SYSTEM | • not simply [a] collection of norms  
• structure of norms  
• relationship to each other  
• vary greatly  
• interrelatedness  
• substantive beliefs  
• systematic  
• tightly linked  
• general statements  
• specific propositions  
• derived  
• the believer  
• [to] refer to the general rule to determine the stance he should take [when] confronted by a new situation  
• high degree of system  
• adjustments |
<p>|       |        | is systematic, … accepts innovation … and is intolerant | SYSTEMATIC, INNOVATIVE, INTOLERANT |
| S.77 Science | is ... a belief system | * [in which] validation comes from empirical events and the ability to systematically relate propositions according to an internally consistent logic * [which] can be reconstructed and perpetuated by any social group with only a few hints, [eg.] the logic of experiment can be applied by anyone who knows it | BELIEF SYSTEM * validation comes from empirical events * the ability to ... relate propositions * systematically * according to [a] ... logic * internally consistent * reconstructed and perpetuated * any social group * logic * experiment * applied * by anyone who knows it |
| S.78 Science | [is or entails] ... knowledge | * the broad field * human * concerned with facts held together by <em>principles</em> (rules) [which are discovered and tested] by the <em>scientific method</em>, an orderly system of solving problems * [which] include * (1) mathematics and logic; * (2) the physical sciences, such as physics and chemistry; * (3) the biological sciences, such as botany and zoology; and * (4) the social sciences, such as sociology and anthropology | KNOWLEDGE * broad field * human * facts * held together by <em>principles</em> (rules) * discovered and tested * scientific method * orderly system * solving problems * mathematics and logic * physical sciences * biological sciences * social sciences |
| S.79 Science | is ... a cultural artefact | * in a sense * [and would have been created differently by] a different society, with a different 'cultural hypothesis' | CULTURAL ARTEFACT * in a sense * created * different society, with a different 'cultural hypothesis' |
| S.80 Science | 1. [is] the state or fact of knowing; knowledge or cognizance ...; or, 1. [is] knowledge | * of something specified or implied * (more or less extensive) as a personal attribute (in Theology and occasionally in Philosophy) | KNOWLEDGE * of something |
| 2a. [is] knowledge | * acquired by study * of any department of learning | KNOWLEDGE * [from] study * of any field |
| 2b. [is] trained skill; |  | SKILL |
| 3a. a particular branch of knowledge or study; a recognised department of learning | * often opposed to *art | KNOWLEDGE * branch of |
| 3b. a craft, trade, or occupation | * requiring trained skill | OCCUPATION |</p>
<table>
<thead>
<tr>
<th>Definition</th>
<th>Study</th>
<th>Knowledge or Intellectual Activity</th>
<th>Natural and Physical Science</th>
<th>Philosophy</th>
<th>Institutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. A branch of study</td>
<td>• which is concerned either with a connected body of demonstrated truths or with observed facts systematically classified • and more or less colligated by being brought under general laws, • and which includes trustworthy methods for the discovery of new truth within its own domain</td>
<td>• of demonstrated truths • observed • facts • systematically classified • colligated by being brought under general laws • trustworthy • methods • for the discovery of new truth • within its own domain</td>
<td>• of which the 'sciences' are examples • which may be learned by study [in an early use of the word, in sense 3] • [as] sciences (in sense 4) as distinguished from other departments of learning [in modern use]</td>
<td>• human, social, political • with complicated histories and relations to the rest of society</td>
<td>• human, social, political • with complicated histories and relations to the rest of society</td>
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<tr>
<td>S.82 Science</td>
<td>[is or entails] scientific method</td>
<td>SCIENTIFIC METHOD</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>• [according to] the commonsensical and 2500 year old story</td>
<td>• commonsensical</td>
<td></td>
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<tr>
<td></td>
<td>• [which entails] a set of assumptions</td>
<td>• a set of</td>
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<tr>
<td></td>
<td>• that have always underpinned and guided Western thinking about scientific method</td>
<td>• assumptions</td>
<td></td>
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<td></td>
<td>• based on the following assumptions:</td>
<td>• have always underpinned and guided</td>
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<td></td>
<td>• Nature is an objective system of facts</td>
<td>• Western</td>
<td></td>
<td></td>
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<td></td>
<td>• Humans can objectively observe and report facts</td>
<td>• thinking</td>
<td></td>
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<td></td>
<td>• Scientific knowledge is based on facts alone</td>
<td>• based on ... assumptions</td>
<td></td>
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<td></td>
<td>• Theories are generalisations of facts and are proven true or 'confirmed' by tests</td>
<td>• Nature</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>• Science makes progress ...</td>
<td>• objective</td>
<td></td>
<td></td>
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<td></td>
<td>• Scientific knowledge is objective and proven, and therefore has no social, personal or political bias</td>
<td>• system</td>
<td></td>
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<tr>
<td></td>
<td>• What science proves true about Nature is the sole basis for technology and social progress.</td>
<td>• facts</td>
<td></td>
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<tr>
<td></td>
<td>• [that is] cultural</td>
<td>• humans</td>
<td></td>
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<td></td>
<td>• [about] scientific method</td>
<td>• objectively</td>
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<tr>
<td></td>
<td>• [that is] vast, cultural</td>
<td>• observe and report</td>
<td></td>
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<tr>
<td>S.83 Science</td>
<td>[is or entails] a ... myth</td>
<td>MYTH</td>
<td></td>
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<tr>
<td></td>
<td>• [that is] cultural</td>
<td>• scientific method</td>
<td></td>
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<tr>
<td></td>
<td>• [about] scientific method</td>
<td>• cultural</td>
<td></td>
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<tr>
<td></td>
<td>• [that is] messy, complex human historical</td>
<td>INSTITUTION</td>
<td></td>
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<tr>
<td></td>
<td>• which has been shaped, and is shaped by cultural, economic and ideological forces</td>
<td>• messy, complex</td>
<td></td>
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<tr>
<td></td>
<td>• [that is] seething social-political</td>
<td>• human historical</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>• [that is] vast, cultural</td>
<td>• shaped by</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>• cultural [forces]</td>
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<td>• economic [forces]</td>
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<td></td>
<td></td>
<td>• ideological forces</td>
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<tr>
<td></td>
<td>is [an] institution</td>
<td>CONTENTION</td>
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<tr>
<td></td>
<td></td>
<td>• seething</td>
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<td></td>
<td></td>
<td>• social-political</td>
<td></td>
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<tr>
<td>S.84 Science</td>
<td>[is or entails] discoveries</td>
<td>DISCOVERIES</td>
<td></td>
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<tr>
<td></td>
<td>• [which] have a structure</td>
<td>• structure</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>• [which have] linkages of certain changes of existing theory with certain specified material practices</td>
<td>• linkages</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• [which] have to do with human interaction with nature, and with human imposing of grids on nature</td>
<td>• certain changes of existing theory</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• [which occur] when a change of human ideas, a change of human cultural belief is associated with certain actions and things in the world</td>
<td>• certain specified material practices</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• which involve human ideas, human theories, human plans, and human practical implementation of those ideas</td>
<td>• have to do with human interaction</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>• [which are] like new product lines</td>
<td>• with nature</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>S.85 [Science]</th>
<th>[is or entails] an enterprise</th>
<th>ENTERPRISE</th>
</tr>
</thead>
<tbody>
<tr>
<td>can be seen as the search</td>
<td>• for algorithmic compressions of observational data</td>
<td>SEARCH</td>
</tr>
<tr>
<td>[is or entails] the goal</td>
<td>• [which is] the production of an abbreviated description of the world based on certain unifying principles we call laws</td>
<td>GOAL</td>
</tr>
<tr>
<td>is predicated upon the belief</td>
<td>• [which avoids] the indiscriminate accumulation of every available fact</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>S.86 Science</th>
<th>[is or entails] progress</th>
<th>PROGRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• [which] requires both reductionistic and holistic approaches</td>
<td>• both reductionistic and holistic</td>
</tr>
<tr>
<td>Science</td>
<td>[is or entails] the idea of a hidden order in nature</td>
<td>• which was mathematical in form and could be uncovered by ingenious investigation</td>
</tr>
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<td>---------</td>
<td>-------------------------------------------------</td>
<td>---------------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• [that as exemplified by Newton’s laws of motion] demands special and systematic measurement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• [and] some sort of abstract theoretical framework</td>
</tr>
<tr>
<td>S. 87</td>
<td>[Science] [is or entails a] type of thinking</td>
<td>• that things are as they are as a result of some sort of logical necessity or inevitability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• mostly [without] God</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• [that] implies that the world forms a closed and complete system of explanation, in which everything is accounted for...</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• [that] also means that in principle we need not actually observe the world to be able to work out its form and content</td>
</tr>
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<td></td>
<td></td>
<td>• [that entails] a crucial assumption: that the world is both rational and intelligible</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• often expressed as the ’principle of sufficient reason’</td>
</tr>
<tr>
<td></td>
<td>[is or entails] an enterprise</td>
<td>• is built upon the assumed rationality of nature</td>
</tr>
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<tr>
<td>S. 88</td>
<td>Science [is or entails] discourse</td>
<td>• [that is one among] other bodies of organised, rational discourse, such as religion, politics, law, or “the humanities”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• [is or entails] knowledge</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• [is or entails] the goal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• which is a consensus of rational opinion over the widest possible field</td>
</tr>
<tr>
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<tr>
<td>[is or entails] the scientific community</td>
<td>[is or entails a] place ... in society at large</td>
<td>SCIENTIFIC COMMUNITY</td>
</tr>
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</tr>
<tr>
<td>• [whose] internal sociology [arises from this] consensus, including • the ways that scientists are educated, choose research topics, communicate with one another, criticise and refine their findings, and relate to one another as members of a specialised social group</td>
<td>• [that entails] economics of research and development • organisation of scientific institutions • priorities and planning of research • agonising ethical dilemmas facing the socially responsible scientist</td>
<td>• internal sociology • consensus • scientists • are educated • choose research topics • communicate • with one another • criticise and refine their findings • relate • to one another • members of a specialised social group</td>
</tr>
</tbody>
</table>

S.89 Science is ... universal and unique • as we often claim UNIVERSAL, UNIQUE • as we often claim

Science is monolithic and monopolistic • [in modern times] • unique roots in seventeenth-century Europe • has effectively eliminated all competitors MONOLITHIC, MONOPOLISTIC • unique roots in seventeenth-century Europe • eliminated all competitors

[Science] [is or entails] activity • self-critical • has not been ... challenged ... independently ACTIVITY • self-critical • not ... challenged ... independently

S.90 Science [is or entails an ] institution • [that is] social [and] unique [in modern times] • in no other civilisation • system of mutually communicating, criticising and socially-interacting observers, dedicated to the principles of consensibility and consensuality INSTITUTION • social • unique • modern • in no other civilisation • system • mutually • communicating • criticising • socially-interacting • observers • dedicated • principles • consensibility and consensuality
<table>
<thead>
<tr>
<th>S.91</th>
<th>[Science]</th>
<th>[is or entails] knowledge</th>
<th>KNOWLEDGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>• stored and communicated in a variety of more or less artificial and formalised languages</td>
<td>• stored</td>
</tr>
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<td></td>
<td></td>
<td>• or as reproducible material maps</td>
<td>• communicated</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• [where] the doorway between the public noetic domain and the private mental domain of each individual is open in the first instance only to messages expressed in the natural language of his particular social group</td>
<td>• artificial</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WORLD PICTURE</td>
<td>• formalised</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• one of many</td>
<td>• languages</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• in the noetic domain</td>
<td>• reproducible</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• not privileged by comparison with any other systematic scheme to which a social group can subscribe</td>
<td>• material maps</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• [on a] strict application of the principles of sociology of knowledge</td>
<td>• public noetic domain</td>
</tr>
<tr>
<td></td>
<td></td>
<td>astonishing revelations of the nature of things, and the attendant metaphysical interpretations which contrast so dramatically with alternative, &quot;non-scientific&quot; world pictures</td>
<td>• private mental domain</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• [in] modern science</td>
<td>• each individual</td>
</tr>
<tr>
<td></td>
<td></td>
<td>KNOWLEDGE</td>
<td>• natural</td>
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<td></td>
<td></td>
<td>• stored</td>
<td>• language</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• communicated</td>
<td>• particular social group</td>
</tr>
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<td>• artificial</td>
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<tr>
<td></td>
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<td>• formalised</td>
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<td></td>
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<td>• languages</td>
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<td></td>
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<td>• reproducible</td>
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<td>• material maps</td>
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<td>• public noetic domain</td>
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<td>• private mental domain</td>
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<td>• each individual</td>
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<td>• natural</td>
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<td>• language</td>
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<td></td>
<td>• particular social group</td>
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<table>
<thead>
<tr>
<th>S.92</th>
<th>Science</th>
<th>is [a] world picture</th>
<th>WORLD PICTURE</th>
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<tbody>
<tr>
<td></td>
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<td>• [but] is no more than one of many</td>
<td>• one of many</td>
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<td>• in the noetic domain</td>
<td>• noetic domain</td>
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<td>• not privileged by comparison with any other systematic scheme to which a social group can subscribe</td>
<td>• not privileged by comparison</td>
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<td>• [on a] strict application of the principles of sociology of knowledge</td>
<td>• with any other</td>
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<td>astonishing revelations of the nature of things, and the attendant metaphysical interpretations which contrast so dramatically with alternative, &quot;non-scientific&quot; world pictures</td>
<td>• systematic scheme</td>
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<td></td>
<td></td>
<td>• [in] modern science</td>
<td>• a social group</td>
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<td></td>
<td>KNOWLEDGE</td>
<td>• subscribe</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• revealed</td>
<td>• [according to] principles of sociology of knowledge</td>
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<td>• of the nature of things</td>
<td>• revelations</td>
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<td>• attendant metaphysical interpretations</td>
<td>• of the nature of things</td>
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<td></td>
<td>• contrast ... with alternative, &quot;non-scientific&quot; world pictures</td>
<td>• attendant metaphysical interpretations</td>
</tr>
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<td></td>
<td></td>
<td>• modern</td>
<td>• contrast ... with alternative, &quot;non-scientific&quot; world pictures</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>S.93</th>
<th>Science</th>
<th>[is or entails] the ... strategy</th>
<th>STRATEGY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>towards the creation of a maximum consensus in the public domain</td>
<td>• creation</td>
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<td></td>
<td>• based on ... a pre-existing mental harmony between independent human beings on at least some matters of common interest</td>
<td>• consensus</td>
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<td>• public domain</td>
<td>• public domain</td>
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<td>• based on ... a pre-existing mental harmony</td>
<td>• based on ... a pre-existing mental harmony</td>
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<td></td>
<td></td>
<td>• between independent human beings</td>
<td>• matters of common interest</td>
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<td>• matters of common interest</td>
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<tr>
<td>Page</td>
<td>Defining Analysis</td>
<td>Natural Text</td>
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<tr>
<td>S.94</td>
<td>[Science]</td>
<td>[is or entails] inquiry * [that includes] observational procedures * patterns of argument * methods of representation and calculation * metaphysical presuppositions * [that are] analysed and discussed [in the philosophy of science] * and the grounds of their validity are evaluated [in the philosophy of science] from the points of view of formal logic, practical methodology, and metaphysics</td>
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<tr>
<td>S.95</td>
<td>Science</td>
<td>[is or entails] scientific method * a definite pattern</td>
<td></td>
</tr>
<tr>
<td>S.96</td>
<td>[Science]</td>
<td>[is or entails] no ... scientific method</td>
<td></td>
</tr>
<tr>
<td>S.97</td>
<td>Science</td>
<td>[is or entails] knowledge * [that is] systematic and formulated * of natural phenomena * based on particular methods of inquiry and thinking</td>
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<td>[is or entails] methods * firmly grounded in attitudes such as open-mindedness and impartiality, such as respect for data tempered with tentativeness about accepting results as final * require a disciplined approach * critical appraisal is a fundamental part * a mixture of theoretical and practical * centred around these particular ways of thinking</td>
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<td></td>
<td>[is or entails] ways of thinking * [which are] used to explain natural phenomena by the development of theoretical models and explanations</td>
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<tr>
<td>S.98</td>
<td>Science</td>
<td>[is or entails] disciplines * wide variety</td>
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<td>or activities * intellectual * wide variety</td>
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<td>[is or entails] statements * [that are] precise * [and] susceptible to some form of empirical verification</td>
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<tr>
<td>S.99</td>
<td>Science</td>
<td>[entails] philosophical aspects * [which] only when philosophy more or less as we now know it became a university specialism in the nineteenth century [were left to] specialist philosophers</td>
<td></td>
</tr>
</tbody>
</table>

INQUIRY
- observational procedures
- patterns of argument
- methods of representation and calculation
- metaphysical presuppositions
- analysed and discussed
- validity ... from logic, practical methodology, and metaphysics [in the philosophy of science]

SCIENTIFIC METHOD
- definite pattern

NO SCIENTIFIC METHOD

KNOWLEDGE
- systematic and formulated
- of natural phenomena
- based on particular methods of inquiry and thinking

METHODS
- attitudes
- open-mindedness and impartiality
- respect for data
- tentativeness about accepting results as final
- disciplined approach
- critical appraisal
- theoretical and practical
- ways of thinking

WAYS OF THINKING
- [which are] used to explain natural phenomena
- development
- theoretical models and explanations

DISCIPLINES
- wide variety

ACTIVITIES
- intellectual
- wide variety

STATEMENTS
- precise
- susceptible to empirical verification

PHILOSOPHICAL ASPECTS
- university specialism [since] nineteenth century
This entry is actually discussing literary and scientific texts, but a close reading reveals an implied summary statement of science.

<table>
<thead>
<tr>
<th>Science</th>
<th>[is or entails] belief</th>
<th>[which is demanded by] statement [or] propositional discourse</th>
<th>BELIEF</th>
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<tr>
<td>S.100</td>
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<td>statement</td>
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<td>propositional discourse</td>
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<td>S.101</td>
<td>[is or entails] laws and theories</td>
<td>[which are] characteristic structures of science in general</td>
<td>LAWS AND THEORIES</td>
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<td></td>
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<td>in that any process or program of empirical, explanatory inquiry would only count as science if it were producing structures that comprise confirmable empirical laws and testable theoretical laws and therefore structures that constitute physical theories</td>
<td>characterisitic structures</td>
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<td>[which is demanded by] statement [or] propositional discourse</td>
<td>process or program of empirical, explanatory inquiry</td>
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<td>would only count as science if producing</td>
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<td>testable theoretical laws</td>
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<td>structures that constitute physical theories</td>
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<tr>
<td>S.102</td>
<td>[is or entails] developments</td>
<td>[in] new directions</td>
<td>DEVELOPMENTS</td>
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<td>[that are] not simply of a cognitive or conceptual nature - new fields of research</td>
<td>new directions</td>
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<td>but also of an institutional character: in fact, both feed back on each other, cognitive developments shaping and being shaped by institutional developments [of which the] four main developments in science and technology today [are]</td>
<td>cognitive or conceptual</td>
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<tr>
<td></td>
<td></td>
<td>scientific labour inside the laboratory is typically being undertaken by interdisciplinary research teams or trans-laboratory networks whose research is less easily divided into the basic-applied dichotomy of the past</td>
<td>new fields</td>
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<td>science and technology have become less easy to distinguish in practice than in the past</td>
<td>of research</td>
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<td>the commercial exploitation of scientific knowledge has become necessary for the survival of firms in certain industrial sectors of the economy, those that are likely to provide the new manufacturing processes and products of the twenty-first century, such as bioscience, information technology and new material sciences</td>
<td>institutional</td>
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<td>science and technology have become subject to a growing promotion, monitoring and regulation by national and international agencies</td>
<td>cognitive developments</td>
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<td>shaping and being shaped by institutional developments</td>
<td>necessary for the survival of firms in certain industrial sectors of the economy</td>
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<td>scientific labour inside the laboratory</td>
<td>new manufacturing processes and products of the twenty-first century</td>
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<td>interdisciplinary research teams</td>
<td>bioscience, information technology and new material sciences</td>
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<td>trans-laboratory networks</td>
<td>subject to growing promotion, monitoring and regulation by national and international agencies</td>
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<td>research is less easily divided into the basic-applied dichotomy of the past</td>
<td>scientific knowledge</td>
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<td>new manufacturing processes and products of the twenty-first century</td>
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<td>trans-laboratory networks</td>
<td>commercial exploitation</td>
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<td>interdisciplinary research teams</td>
<td>subject to growing promotion, monitoring and regulation by national and international agencies</td>
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<td>trans-laboratory networks</td>
<td>commercial exploitation</td>
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<td>new manufacturing processes and products of the twenty-first century</td>
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<td>subject to growing promotion, monitoring and regulation by national and international agencies</td>
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<tr>
<td></td>
<td></td>
<td>trans-laboratory networks</td>
<td>commercial exploitation</td>
</tr>
</tbody>
</table>
| S.103 Science | is ... [a] quest | • ever-unfinished  
• to discover facts and establish relationships between them | QUEST  
• ever-unfinished  
• to discover facts  
• establish relationships between them |
| --- | --- | --- | --- |
| [is or entails] the main business | • to trace in the chaos and flux of phenomena a consistent structure with order and meaning, that is, to interpret and to transcend direct experience | MAIN BUSINESS  
• to trace  
• in the chaos and flux of phenomena  
• consistent structure with order and meaning  
• interpret  
• transcend  
• direct experience |
| [is or entails] efforts | • our most persistent intellectual  
• as in art and philosophy  
• are directed toward the discovery of pattern, order, system, structure, whether it be as primitive as the discernment of recurring seasons or as sweeping as a cosmological synthesis | EFFORTS  
• our most persistent intellectual  
• as in art and philosophy  
• are directed toward  
• discovery  
• of pattern, order, system, structure  
• discernment  
• of recurring seasons  
• cosmological synthesis |
| [is or entails] the attempt | • to understand the world of experience in each of its aspects  
• [which is] but one facet of the great intellectual adventure | ATTEMPT  
• understand  
• the world of experience  
• but one facet  
• intellectual adventure |
| [is or entails] the motivations of the investigators | • [which separate] the sciences from the nonsciences | MOTIVATIONS OF THE INVESTIGATORS  
• [which separate] the sciences from the nonsciences |
| [is or entails] concepts and rules ... and the type of argument | • [which separate] the sciences from the nonsciences  
• the scientist uses | CONCEPTS, RULES, TYPE OF ARGUMENT  
• [which separate] the sciences from the nonsciences  
• the scientist uses |
| [is or entails] a set of ... schemes | • [which separate] the sciences from the nonsciences  
• [which] accumulate in science  
• in the course of time  
• despite great innovation and revolutions  
• [which are] internationally acceptable, basic, and fairly enduring conceptual  
• [which] can hardly be said for many other human endeavours | SET OF SCHEMES  
• [which separate] the sciences from the nonsciences  
• accumulate  
• in the course of time  
• innovation and revolutions  
• internationally acceptable  
• basic  
• fairly enduring  
• conceptual  
• other human endeavours |
| S.104 Science | [is or entails] methods | • [meaning] the sequence and rule by which scientists now and in the past have actually done their work
• as for every task, there are here not one but many methods and uncountable variants
• even these different methods are usually read into the story after the work has been completed, and so reflect the actual working procedures only in a rather artificial and debatable way | METHODS
• sequence
• rule
• by which scientists
• now and in the past
• have actually done their work
• as for every task
• many methods and uncountable variants
• read into the story
• after the work has been completed
• actual working procedures
• rather artificial and debatable way |
| S.105 Science | [is or entails] knowledge | • [which is] an historically evolving body | KNOWLEDGE
• historically evolving body |
| | [is or entails] theory | • [which] can only be adequately appraised if due attention is paid to its historical context
• [and whose] appraisal is intimately linked with the circumstances under which a theory first makes its appearance | THEORY
• can only be adequately appraised if
• historical context
• circumstances under which a theory first makes its appearance |
| | [is or entails] thought | • [that is] evolving | THOUGHT
• evolving |
| | [is or entails] a picture | • [that is] broad and coherent
• of the universe and of life in it
• incomplete
• in some aspects open to serious question
• the best picture available | PICTURE
• broad and coherent
• of the universe and ... life
• incomplete
• open to ... question
• best picture available |
| | [is or entails a] process | • of unification
• [that] has not been restricted to the integration of beliefs about the world
• [but also concerns] those beliefs with the methods employed to attain well-grounded beliefs | PROCESS
• unification
• restricted
• integration
• beliefs
• about the world |
| | [is or entails] methods | • for arriving at well-grounded beliefs about the world
• have come more and more to be shaped by those very beliefs
• [and that] have evolved with the evolution of knowledge | METHODS
• well-grounded beliefs about the world
• shaped
• by those very beliefs
• evolved
• evolution
• knowledge |
| | knowledge and ... methods | • [methods] of gaining knowledge
• [that are] intimately related
• [that] flies in the face of the traditional sharp bifurcation between the two | KNOWLEDGE, METHODS
• gaining knowledge
• intimately related
• traditional
• sharp bifurcation of the two |
<table>
<thead>
<tr>
<th>Sciences</th>
<th>[are or entail or inhere in] knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>[is or entails a] method</td>
<td>• [that] is, and has long been, commonly assumed [to be] a unique method, the 'scientific' or 'empirical' or 'experimental' method</td>
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<tr>
<td></td>
<td>• allegedly discovered or at least first systematically applied in the seventeenth century</td>
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<td>• formulated wholly independently of, and is wholly unaffected by, the knowledge which is arrived at by its means</td>
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<td>• as though ... a set of abstract and immutable rules, like the rules of chess, independent of the strategies of the game but governing what strategies are possible</td>
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<td></td>
<td>• [no] agreement as to precisely what that method is</td>
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<td>• an eternal scientific method which, once discovered, needs only to be applied to generate knowledge</td>
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<td>• [about which] the most strenuous efforts of scientists and philosophers have failed to produce agreement</td>
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<td></td>
<td>• will not alter in the light of that knowledge</td>
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<td></td>
<td>• empty or false [theories]</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>KNOWLEDGE</th>
<th>• produced</th>
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<tbody>
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<td></td>
<td>• scientific era</td>
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<td>• outcome</td>
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<td>• specific interaction</td>
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<td>• of the sciences</td>
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<td>• relation of science to technology</td>
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<td>[relation of science to] philosophy</td>
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<td>[relation of science to] art</td>
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<td>[relation of science to] other intellectual and practical concerns</td>
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<td>• relation between science and technology</td>
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<td>• relations between the sciences</td>
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<td>• alter with each change</td>
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<td>• formation</td>
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<td>• knowledge</td>
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<td>• new constellations</td>
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<td>• new period</td>
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<td>• dispersed</td>
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<td></td>
<td>• knowledge</td>
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<td>• changes again</td>
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<thead>
<tr>
<th>DISCOURSE</th>
<th>• long been, commonly</th>
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<td></td>
<td>• assumed</td>
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<td>• unique</td>
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<td>• method</td>
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<td>• empirical</td>
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<td>• experimental</td>
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<td>• discovered or at least ... applied</td>
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<td>• first ... in the seventeenth century</td>
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<td>• applied</td>
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<td>• systematically</td>
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<td>• wholly independently of, and ... unaffected by</td>
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<td>• knowledge</td>
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<td>• arrived at by its means</td>
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<td>• abstract and immutable rules</td>
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<td>• eternal scientific</td>
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<td>• in the light of that</td>
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<td>• empirical</td>
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<td>• experimental</td>
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<td>• discovered or at least ... applied</td>
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<td>• first ... in the seventeenth century</td>
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<td>• applied</td>
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<td>• systematically</td>
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<td>• formulated</td>
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<td>• wholly independently of, and ... unaffected by</td>
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<td>• knowledge</td>
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<td>• arrived at by its means</td>
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<td>• set</td>
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<td>• abstract and immutable rules</td>
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<td>• independent of</td>
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<td>• governing</td>
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<td>• once [discovered]</td>
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<td>• applied to generate</td>
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<td>• of scientists and philosophers</td>
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<td>• knowledge</td>
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<td></td>
<td>• empty or false</td>
</tr>
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<td></td>
<td>• theories</td>
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<tr>
<td>S.107</td>
<td>[are or entail or inhere in] practice</td>
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<td>--------------------------------------</td>
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<tr>
<td>The sciences</td>
<td>• [at] present&lt;br&gt;• [as officially conceived]&lt;br&gt;• is largely anachronistic&lt;br&gt;• still influential&lt;br&gt;• for the university system&lt;br&gt;• is ... formally administered according to it&lt;br&gt;• Historically&lt;br&gt;• it derives from&lt;br&gt;• latter phase of the Classical scientific era of the nineteenth and early twentieth centuries&lt;br&gt;• For some time&lt;br&gt;• the departmental system&lt;br&gt;• has ceased&lt;br&gt;• any real cognitive relevance&lt;br&gt;• to the actual research activities&lt;br&gt;• going on within university confines or outside in the research institutions&lt;br&gt;• in the contemporary era of science&lt;br&gt;• this now Classic scientific disposition has lost its meaning</td>
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<thead>
<tr>
<th>S.108</th>
<th>[are or entail a] disposition</th>
<th>PRACTICE</th>
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<tbody>
<tr>
<td>The sciences</td>
<td>• [comprising] elements&lt;br&gt;• contemporary&lt;br&gt;• a long time in the making&lt;br&gt;• Only the constellations are relatively new&lt;br&gt;• that is, the conjunction of all these elements as a dominant system of sciences&lt;br&gt;• the main characteristics of contemporary World science back into the nineteenth century&lt;br&gt;• forms of technification, formalisation, abstraction, problem-solving and finalisation have always been there to some degree</td>
<td>DISPOSITION&lt;br&gt;• elements&lt;br&gt;• contemporary&lt;br&gt;• long time&lt;br&gt;• making&lt;br&gt;• constellations&lt;br&gt;• relatively new&lt;br&gt;• conjunction&lt;br&gt;• elements&lt;br&gt;• dominant&lt;br&gt;• system&lt;br&gt;• contemporary&lt;br&gt;• World science&lt;br&gt;• nineteenth century&lt;br&gt;• technification&lt;br&gt;• formalisation&lt;br&gt;• abstraction&lt;br&gt;• problem-solving&lt;br&gt;• finalisation&lt;br&gt;• always been there</td>
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<tr>
<th>S.109</th>
<th>is ... activity</th>
<th>ACTIVITY</th>
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<tbody>
<tr>
<td>Science</td>
<td>• [that is] social&lt;br&gt;• whose aim is&lt;br&gt;• the production of the knowledge&lt;br&gt;• of the kinds and ways of acting of independently existing and active things</td>
<td>social&lt;br&gt;• aim&lt;br&gt;• production&lt;br&gt;• knowledge&lt;br&gt;• acting&lt;br&gt;• of independently existing and active things</td>
</tr>
</tbody>
</table>
| S.110 Science | [was or entailed] pursuit | • [but] no longer  
• [that was] marginal [and] of little practical use carried on by a handful of enthusiasts  
• and it no longer needs to justify itself by a direct answer to the challenge of other fields of knowledge claiming exclusive access to the truth. | PURSUIT  
• no longer  
• marginal  
• little practical use  
• carried on  
• handful of enthusiasts  
• no longer  
• other fields  
• knowledge  
• access  
• truth |
|---|---|---|---|
| [is or entails a] world | • [that] has grown in size and in power  
• [whose] problems have changed from the epistemological to the social | WORLD  
• changed  
• problems  
• epistemological  
• social  
• world of science  
• grown |
| [is or entails] knowledge | • [whose] character [is] embodied in a particular scientific result [that] is largely independent of the social context of its first achievement  
• [whose] increase and improvement ... is a very specialised and delicate social process  
• whose continued health and vitality under new conditions is by no means to be taken for granted | KNOWLEDGE  
• embodied  
• scientific  
• result  
• independent  
• social context  
• achievement  
• increase and improvement  
• social  
• process  
• new conditions  
• taken for granted |
| [is or entails growth] | • to its present size and importance through its application to the solution of other sorts of problems, and these extensions react back on science and become part of it  
• [which to understand] we must consider those sorts of disciplined inquiry whose goals include power as well as knowledge. | GROWTH  
• present size and importance  
• application  
• solution of  
• react  
• become  
• disciplined  
• inquiry  
• goals  
• power  
• knowledge |
<table>
<thead>
<tr>
<th>Science</th>
<th>[is or entails growth]</th>
<th>GROWTH</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>[that is] so much faster than mere people</td>
<td>faster than mere people</td>
</tr>
<tr>
<td></td>
<td>because old knowledge breeds new</td>
<td>old</td>
</tr>
<tr>
<td></td>
<td>[and] very recent knowledge breeds new so much faster than it does when it later becomes packed down into the archive</td>
<td>knowledge</td>
</tr>
<tr>
<td></td>
<td>[that happens] very regularly, in a very structured way, and from its epidermis rather than from its body</td>
<td>breeds</td>
</tr>
<tr>
<td></td>
<td>[in] the normal growth pattern of scientific research and most published work</td>
<td>new</td>
</tr>
<tr>
<td></td>
<td>[but] not usually happen [as] the ab initio growth of new knowledge coming from almost nowhere [such as] the native genius of isolated minds.</td>
<td>very recent</td>
</tr>
<tr>
<td></td>
<td>[that] becomes packed down into the archive</td>
<td>packed down</td>
</tr>
<tr>
<td></td>
<td>[regularly]</td>
<td>into the archive</td>
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<tr>
<td></td>
<td>[structured way]</td>
<td>relatively</td>
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<tr>
<td></td>
<td>[from its epidermis rather than from its body]</td>
<td>structured way</td>
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<tr>
<td></td>
<td>[that happens] very regularly, in a very structured way, and from its epidermis rather than from its body</td>
<td>from its epidermis rather than from its body</td>
</tr>
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<td></td>
<td>[that happens] very regularly, in a very structured way, and from its epidermis rather than from its body</td>
<td>normal</td>
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<td></td>
<td>[in] the normal growth pattern of scientific research and most published work</td>
<td>growth</td>
</tr>
<tr>
<td></td>
<td>[but] not usually happen [as] the ab initio growth of new knowledge coming from almost nowhere [such as] the native genius of isolated minds.</td>
<td>pattern</td>
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<td></td>
<td>[that] becomes packed down into the archive</td>
<td>scientific</td>
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<td></td>
<td>[regularly]</td>
<td>research</td>
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<td></td>
<td>[structured way]</td>
<td>published work</td>
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<td></td>
<td>[from its epidermis rather than from its body]</td>
<td>growth</td>
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<tr>
<td></td>
<td>[that happens] very regularly, in a very structured way, and from its epidermis rather than from its body</td>
<td>from almost nowhere</td>
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<td>[in] the normal growth pattern of scientific research and most published work</td>
<td>native genius of isolated minds</td>
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<th>[is or entails innovation]</th>
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<td>knowledge</td>
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<td>published</td>
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<td></td>
<td>[is or entails innovation]</td>
<td>in scientific papers</td>
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<td></td>
<td>innovation</td>
<td>new</td>
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<td></td>
<td>[is or entails innovation]</td>
<td>facts</td>
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<td></td>
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<td>experiments</td>
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<td>[is or entails innovation]</td>
<td>theories</td>
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<td>old ones</td>
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<td></td>
<td>[is or entails innovation]</td>
<td>structured</td>
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<th>[is or entails papers]</th>
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<td></td>
<td>[is or entails papers]</td>
<td>counted</td>
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<td>papers</td>
<td>manipulated</td>
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<td></td>
<td>[is or entails papers]</td>
<td>published</td>
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<td>[is or entails papers]</td>
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<td>in the World List of Scientific Periodicals</td>
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<td>[is or entails papers]</td>
<td>knitted research-front structure</td>
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<th>[is or entails structure]</th>
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<td>structure</td>
<td>other periodicals</td>
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<tr>
<td></td>
<td>[is or entails structure]</td>
<td>World List</td>
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</table>
| **S.113**  
| Science | **S.114**  
| [is or entails] theories | [is or entails] institutional imperatives |  
|  
| • [that] are ways of looking at the world  
| • [that affect] our general beliefs and expectations  
| • and thereby also our experiences and our conceptions of reality  
| • [so that] what is regarded as 'nature' at a particular time is our own product in the sense that all the features ascribed to it have first been invented by us and then used for bringing order into our surroundings  
|  
| • [in] modern times  
| • sets  
| • universalism, communism, disinterestedness, organised scepticism  
| • [In universalism] truth claims ... are to be subjected to preestablished impersonal criteria: consonant with observation and with previously confirmed knowledge  
| • [In communism] the substantive findings of science are a product of social collaboration and are assigned to the community  
| • [Disinterestedness entails] a distinctive pattern of institutional control of a wide range of motives which characterises the behaviour of scientists  
| • [Organised scepticism entails] the suspension of judgement until 'the facts are at hand' and the detached scrutiny of beliefs in terms of empirical and logical criteria  
|  
| • [in the sense of] content and not to the human arrangements for arriving at it of cognitions, that is, of true experiential statements  
| • [not] philosophy  
|  
| • [that is] rational  
|  
| **THEORIES**  
| • ways of looking  
| • at the world  
| • general beliefs and expectations  
| • experiences  
| • conceptions  
| • of reality  
| • used  
| • for bringing [order]  
| • order  
|  
| **INSTITUTIONAL IMPERATIVES**  
| • modern  
| • sets  
| • universalism  
| • communism  
| • disinterestedness  
| • organised  
| • scepticism  
| • truth claims  
| • subjected  
| • preestablished  
| • impersonal  
| • criteria  
| • observation  
| • previously  
| • confirmed  
| • knowledge  
| • social  
| • collaboration  
| • assigned  
| • community  
| • pattern  
| • institutional  
| • control  
| • motives  
| • behaviour  
| • scientists  
| • suspension of judgement  
| • detached  
| • scrutiny  
| • beliefs  
| • empirical  
| • logical  
| • criteria  
|  
| **SYSTEM**  
| • content  
| • not the human [arrangements]  
| • arrangements  
| • cognitions  
| • true  
| • experiential  
| • statements  
| • [not] philosophy  
|  
| **ENDEAVOUR**  
| • rational  
| • rational
| S.117 Science | is or entails | criticism | such as particular claims and arguments | • that become smaller and more focused | • in the natural sciences | • over time | • [where] a community of inquirers share enough assumptions that they can devote their energies to solving well-defined puzzles | CRITICISM | • claims and arguments | • smaller and more focussed | • natural sciences | • over time | • community of inquirers | • assumptions | • solving ... puzzles | • well-defined |
| S.118 Science | is or entails | work | the organisational, instrumental and cognitive - in short, people, machines and ideas | • the organisation of science [is] the socio-political system and institutional arrangements under which science is produced | • [the] instrumentation [is] the new technological machinery and the new techniques of research made available in all the sciences | • the cognitive changes [are] the new theories, ideas and hypotheses, which, although altered, were largely developments of previous ones | WORK | • organisational | • instrumental | • cognitive | • people | • machines | • ideas | • socio-political system | • institutional arrangements | • produced | • new | • technological machinery | • techniques | • research | • theories | • ideas | • hypotheses | • developments | • previous ones |
| S.119 Science | is or entails | knowledge | • [which is] social | • and once a theory, hypothesis, or set of data has been accepted by a community, it becomes a public resource | • to use in support of other theories and hypotheses and as a basis of action. | • [and] is social both in the ways it is created and in the uses it serves | KNOWLEDGE | • social | • produced | • processes | • theory | • hypothesis | • set | • data | • accepted | • community | • public resource | • use | • in support | • action | • created | • uses it serves |
| S.120 Science | [is or entails a] procedure | • [that is] the scientific method of investigating the world  
• [that is] immensely powerful  
• for helping us to understand the complex universe in which we live  
• [and has] enormous power and scope  
• [and] uncompromising honesty  
• [that requires passing] rigorous tests of approval by the scientific community [for] every new discovery, every theory … to pass  
• [that] generally … leads us in the direction of reliable knowledge | PROCEDURE  
• scientific method  
• investigating  
• the world  
• powerful  
• understand  
• the complex universe in which we live  
• power and scope  
• honesty  
• rigorous  
• tests of approval  
• scientific community  
• new  
• discovery  
• theory  
• leads  
• reliable  
• knowledge |
| S.121 Science | is [or entails] disciplines | • [of which there are] a wide variety | DISCIPLINES  
• variety |
|  | is [or entails] activities | • [of which there are] a wide variety  
• [that are] intellectual | ACTIVITIES  
• variety  
• intellectual |
|  | is [or entails] making | • making precise statements which are susceptible to some sort of check or proof  
• [which] often implies that the situations with which the special science is concerned can be made to recur in order to submit themselves to check | MAKING  
• statements  
• precise  
• check  
• proof  
• special  
• made to recur  
• submit  
• check |
|  | [is or entails observations] | • [as in] astronomy or geology  
• in which repetition of a situation at will is intrinsically impossible, and the possible precision is limited to precision of description  
• [where] the subject matter of the individual science is something in the world of phenomena | OBSERVATIONS  
• astronomy  
• geology  
• repetition  
• intrinsically impossible  
• precision  
• description  
• individual  
• the world of phenomena |
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<th>Science</th>
<th>Knowledge</th>
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**Science**

- [sometimes is or entails either exactitude or description]
  - [where] examples of the former are physics and, to a lesser degree, chemistry; and of the latter, taxonomical botany or zoology
  - [where] the exact sciences are in general characterised by the possibility of exact measurement, [where] measurement is fundamentally description given by the use of numbers
  - [that studies] systems subject to exact measurement [and] mathematical analysis: this susceptibility is one of the most important characteristics of the exact sciences
  - [and alternatively] one of the most important tasks of a descriptive science is to develop a method of description or classification that will permit precision of reference to the subject matter

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<th>Knowledge</th>
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- [is or entails] means
  - of solving problems [which] emphasises its instrumental aspect
  - [and thus] viewed as closely connected with technology
  - [with] economic and political [characteristics]
  - [and therefore] should be used wisely and well [which] puts it into the open arena of social conflict

- [which is] organised
  - [and] archival
  - [comprising] information about natural phenomena
  - [which is] acquired by research, organised into coherent theoretical schemes, and published in books and journals
  - [and] is often profoundly influential through its technological applications
  - a politically neutral, public resource
  - a significant historical process

**Exactitude, or Description**

- physics
- chemistry
- taxonomical botany
- taxonomical zoology
- exact
- measurement
- description
- use of numbers
- [that studies] systems
- mathematical analysis
- method of description
- [method of] classification
- [precision of] reference
- reference

**Knowledge**

- organised
- archival
- information
- about natural phenomena
- acquired
- research
- organised
- coherent theoretical schemes
- published
- books and journals
- influential
- technological applications
- politically neutral, public resource
- historical
- process
<p>| [is or entails] methodology | • such as experimentation, observation and theorising • are considered elements of a special method for obtaining reliable information about the natural world • [and] from this point of view, science may be regarded as essentially objective, and hence transcending all political considerations |
| [is or entails] discovery | • by people with a special gift for research • [involving] such important personal aptitudes as curiosity and intelligence • [suggesting] that scientists should be recognised as members of a distinct profession, of considerable political significance |
| [is or entails] product | • of research • [which] does employ characteristic methods |
| [is or entails] a body of knowledge | • [that is] organised |
| [is or entails] a means | • of solving problems |
| [is or entails] an institution | • [that is] social • [and] needs material facilities |
| [is or entails] a theme | [that is] educational |
| [is or entails] a resource | • [that is] cultural [and] requires to be managed; |
| [is or entails] affairs | • [that are] human |
| [is or entails] the discipline | • of determining relations of relevance and irrelevance |</p>
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<th>Development</th>
<th>Criteria</th>
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<tbody>
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<td>[is or entails]</td>
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<td>[consisting largely]</td>
<td>of</td>
</tr>
<tr>
<td>development</td>
<td>beginning with suppositions</td>
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<tr>
<td>[is or entails]</td>
<td>about what is and is not</td>
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<td>development</td>
<td>relevant to a certain claim</td>
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<tr>
<td>[is or entails]</td>
<td>and of gradually refining the</td>
</tr>
<tr>
<td>development</td>
<td>claim and our understanding</td>
</tr>
<tr>
<td>[is or entails]</td>
<td>of what is relevant to it and</td>
</tr>
<tr>
<td>development</td>
<td>what is not</td>
</tr>
<tr>
<td>[is or entails]</td>
<td>[namely] shedding certain</td>
</tr>
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<td>development</td>
<td>beliefs as irrelevant</td>
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<tr>
<td>[is or entails]</td>
<td>[and] introducing new ones</td>
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<tr>
<td>development</td>
<td>which we find to be more so</td>
</tr>
<tr>
<td>[is or entails]</td>
<td>of refining our modes of</td>
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<td>conceiving and describing the</td>
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<tr>
<td>[is or entails]</td>
<td>world around us so as to</td>
</tr>
<tr>
<td>development</td>
<td>bring out more clearly and</td>
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<tr>
<td>[is or entails]</td>
<td>firmly the ways in which</td>
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<tr>
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<td>things are related to one another</td>
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<tr>
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<tr>
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<td>of what is to count as a reason</td>
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<td>[which] we do not have in</td>
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<tr>
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<tr>
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<td>we can do things with certain</td>
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<tr>
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<tr>
<td>[is or entails]</td>
<td>we [can] understand material</td>
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<td>substances in terms of what they</td>
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<tr>
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<tr>
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<td>and looking for constituents then</td>
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<tr>
<td>development</td>
<td>became a standard method and</td>
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<tr>
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<td>criterion of success in</td>
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<td>of relevance</td>
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<td>[which] we do not have in</td>
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<tr>
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<tr>
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<td>we can do things with certain</td>
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<td>approaches</td>
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<td>[is or entails]</td>
<td>we [can] understand material</td>
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<td>substances in terms of what they</td>
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<td>[is or entails]</td>
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<tr>
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<td>became a standard method and</td>
</tr>
<tr>
<td>[is or entails]</td>
<td>criterion of success in</td>
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<td>development</td>
<td>understanding</td>
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<td>Science activities</td>
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<td><em>of developing such standards or criteria</em></td>
<td><em>[that are] not a homogeneous set</em></td>
</tr>
<tr>
<td><em>[that is] ... complex</em></td>
<td><em>[that includes] science for understanding and science for manipulation</em></td>
</tr>
<tr>
<td><em>[consisting partly of] a revision of our descriptive language to bring out better what we have learned</em></td>
<td><em>[whose] styles and motivation are different.</em></td>
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<tr>
<td><em>[and] our ways of learning about nature</em></td>
<td><em>[that is], our coming to know about the world</em></td>
</tr>
<tr>
<td><em>[that is], our coming to know about the world</em></td>
<td><em>[and] of learning how to learn, to think, and to talk about nature</em></td>
</tr>
<tr>
<td><em>[even though] we may ... turn out to have been wrong or misguided or confused in the beliefs we have arrived at, or the standards of rationality we have forged, or the understanding we have developed of what it is to understand</em></td>
<td><em>[even though] we may ... turn out to have been wrong or misguided or confused in the beliefs we have arrived at, or the standards of rationality we have forged, or the understanding we have developed of what it is to understand</em></td>
</tr>
<tr>
<td><em>[that is], the possibility of doubt and error is always open; but we do have, or at least develop, better and worse hypotheses about what are better and worse hypotheses, methods, descriptions</em></td>
<td></td>
</tr>
</tbody>
</table>

**UNDERSTANDING**
- expression
- human
- curiosity
- devise
- intellectually graspable model
- of the natural world
- think
- coherently
- the things we [observe]
- observe
- development
- intellectual models
- sense of wonder
- creative
- judged
- compatibility
- observed
- facts
- prediction
- simplicity
- elegance
- tests
- aesthetic

**ACTIVITIES**
- homogeneous set
- for [understanding]
- understanding
- for [manipulation]
- manipulation
- styles
- motivation

**PROCESS**
- developing
- standards or criteria
- complex
- revision
- descriptive
- language
- learned
- ways of learning
- about nature
- know
- about the world
- learning
- learn
- think
- talk
- about nature
- beliefs
- standards of rationality
- understanding
- of what it is to understand
- doubt
- error
- develop
| [is or entails a] search | • for understanding  
| | • justified by the greater power it  
| | • source of enlightenment and  
| | • confinement on humankind  
| | • expression of the human spirit  | SEARCH  
| | • understanding  
| | • justified  
| | • power  
| | • humankind  
| | • enlightenment  
| | • liberation  
| | • expression  
| | • human spirit  |
| [is or entails motivation] | This is not to suggest that  
| | science motivated by the  
| | desire to manipulate aspects  
| | of the world in which we live  
| | has nothing in common with  
| | science for understanding or  
| | that it does not have a  
| | legitimate place among  
| | human’s activities, but rather  
| | that their purposes are  
| | different, the attitudes of mind  
| | of those who practise them  
| | may well conflict, and above  
| | all that science for  
| | manipulation must be  
| | justified by its results. It  
| | should be required to  
| | demonstrate that the benefits  
| | it confers on humankind  
| | outweigh their costs -  
| | material, social and spiritual  | MOTIVATION  
| | • desire  
| | • manipulate  
| | • of the world  
| | • understanding  
| | • human’s  
| | • activities  
| | • purposes  
| | • attitudes of mind  
| | • of those who  
| | • practise  
| | • for [manipulation]  
| | • manipulation  
| | • justified  
| | • demonstrate  
| | • benefits  
| | • humankind  
| | • material  
| | • social  
| | • spiritual  |
| S.125 Science | [is or entails] method  
| | • [that is] scientific  
| | • [and in particular] the aims of  
| | • scientific activity  
| | • about its history  | METHOD  
| | • scientific  
| | • aims  
| | • history  |
| [is or entails] activity | • [that has an] aim  
| | • for clearly, different scientists  
| | • have different aims, and  
| | • science itself (whatever that  
| | • may mean) has no aims  
| | • yet … there is something  
| | • characteristic of scientific  
| | • activity  
| | • [that] looks pretty much like a  
| | • rational activity, and since a  
| | • rational activity must have  
| | • some aim, the attempt to  
| | • describe the aim of science  
| | • may not be entirely futile  | ACTIVITY  
| | • aim  
| | • scientists  
| | • activity  
| | • rational  |
| [is or entails an] aim | • to find satisfactory explanations  
| | of whatever strikes us as  
| | being in need of explanation  
| | • [where] an explanation (or a  
| | causal explanation) is meant a  
| | set of statements one of  
| | which describes the state of  
| | affairs to be explained …  
| | while the others, the  
| | explanatory statements, for  
| | the “explanation” in the  
| | narrower sense of the word  | AIM  
| | • satisfactory  
| | • explanations  
| | • causal  
| | • set  
| | • statements  
| | • describes  
| | • the state of affairs  
<p>| | • explained  |</p>
<table>
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<tr>
<th>S.126 Science</th>
<th>[is or entails] culture</th>
<th>[is or entails] understanding</th>
<th>[is or entails] endeavour</th>
</tr>
</thead>
<tbody>
<tr>
<td>* [that is] human&lt;br&gt;• scientific findings ... are meaningless outside their cultural context&lt;br&gt;• [where] a theoretical science unaware that those of its constructs considered relevant and momentous are destined eventually to be framed in concepts and words that have a grip on the educated community and become part and parcel of the general world picture&lt;br&gt;• where the initiated continue musing to each other in terms that are, at best, understood by a small group of close fellow travellers, will necessarily be cut off from the rest of cultural mankind&lt;br&gt;• in the long run it is bound to atrophy and ossify however virulently esoteric chat may continue within its joyfully isolated groups of experts</td>
<td>* about the physical, biological, psychological, and social worlds&lt;br&gt;• over the course of human history, people have developed many interconnected and validated ideas&lt;br&gt;• successive generations to achieve an increasingly comprehensive and reliable understanding of the human species and its environment&lt;br&gt;• particular ways of observing, thinking, experimenting, and validating&lt;br&gt;• fundamental aspect of the nature of science&lt;br&gt;• other modes of knowing.</td>
<td>* [with] mathematics, and technology&lt;br&gt;• although each of these human enterprises has a character and history of its own, each is dependent on and reinforces the others</td>
<td></td>
</tr>
</tbody>
</table>
| Science | [is or entails a] world view | • not something that working scientists spend a lot of time discussing  
• they just do science  
• but underlying their work are several beliefs that are not always held by nonscientists  
• [namely] that by working together over time, people can in fact figure out how the world works  
• [and] that the universe is a unified system and knowledge gained from studying one part of it can often be applied to other parts  
• [and] that knowledge is both stable and subject to change. | WORLD VIEW  
• working  
• scientists  
• a lot of time  
• discussing  
• do science  
• work  
• beliefs  
• nonscientists  
• working  
• over time  
• figure out  
• how the world works  
• the universe  
• knowledge  
• studying  
• applied  
• stable  
• subject to change |
| Science | [is or entails] inquiry | • [that is] more complex than popular conceptions would have it  
• process  
• making a great many careful observations and then organising them  
• more flexible than the rigid sequence of steps commonly depicted in textbooks as "the scientific method"  
• more than just "doing experiments"  
• not confined to laboratories  
• imagination and inventiveness  
• scientific inquiry  
• [where] strict logic and empirical evidence must have their day  
• [where] individual investigators working alone sometimes make great discoveries, but the steady advancement of science depends on the enterprise as a whole. | INQUIRY  
• complex  
• process  
• making  
• observations  
• organising  
• flexible  
• rigid sequence of steps  
• the scientific method  
• doing experiments  
• laboratories  
• imagination and inventiveness  
• inquiry  
• logic  
• logic and empirical evidence  
• individual investigators  
• working  
• make great discoveries  
• enterprise as a whole |
| Science | [is or entails] activity | • [that is] of the contemporary world and distinguishes present times from earlier periods  
• [and] an endeavour for learning how the world works  
• [that] provides a living for a very large number of people | ACTIVITY  
• contemporary world  
• present times  
• earlier periods  
• endeavour  
• for [learning]  
• learning  
• how the world works  
• people |
<p>| Science | [is or entails an] enterprise | • [that includes] basic and applied natural and social science, basic and applied mathematics, and engineering and technology, and their interconnections | ENTERPRISE |</p>
<table>
<thead>
<tr>
<th>[is or entails] ideas and practice</th>
<th>* [together with] mathematics and technology are ... closely intertwined</th>
<th>IDEAS, PRACTICE</th>
</tr>
</thead>
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<tr>
<td></td>
<td></td>
<td>• mathematics</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• technology</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• intertwined</td>
</tr>
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</table>
### Analysis of classes determined from Table A.1 (Tables A.2 to A.8)

#### Table A.2
Classes of the subject Science
found in summary statements in Table A.1

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<td>UNDERSTANDING</td>
<td>18, 124, 127</td>
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<td>89</td>
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<td>USES</td>
<td>67</td>
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<td>VALUES AND MORES/VALUE</td>
<td>30, 31</td>
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<td>POSTURE</td>
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<td>VISION</td>
<td>61</td>
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<td>WISDOM</td>
<td>25</td>
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<tr>
<td>WORK</td>
<td>118</td>
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<td>WORLD/WORLD PICTURE/WORLD</td>
<td>16, 73, 74, 92, 110, 128</td>
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<td>VIEW</td>
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Table A.3
Classes of subjects from Table A.2 which indicate that science is characterised by knowledge or concepts

<table>
<thead>
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<th>Classes of subjects</th>
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<td>COMMON SENSE</td>
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<td>CONCEPTS</td>
<td>103</td>
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<td>CONCLUSIONS</td>
<td>14</td>
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<td>FACTS</td>
<td>15, 56</td>
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<td>IDEAS</td>
<td>131</td>
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<td>INFORMATIVE CONTENT</td>
<td>42</td>
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<tr>
<td>KNOWLEDGE</td>
<td>1, 1, 1, 1, 4, 5, 12, 14, 16, 21, 22, 24, 29, 30, 37, 37, 47, 49, 50, 54, 54, 78, 80, 80, 80, 80, 88, 91, 92, 97, 104, 105, 106, 110, 119, 122, 122</td>
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<tr>
<td>KNOWLEDGE OR INTELLECTUAL ACTIVITY</td>
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<td>NOTIONS</td>
<td>36</td>
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<tr>
<td>TRUTH</td>
<td>52</td>
</tr>
<tr>
<td>UNDERSTANDING</td>
<td>18, 124, 127</td>
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### Table A.4

**Classes of subjects from Table A.2 which indicate that science is characterised by activity**

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<thead>
<tr>
<th>Class of Subjects</th>
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<tr>
<td><strong>Acquisition</strong></td>
<td>34</td>
</tr>
<tr>
<td><strong>Activities/Activity</strong></td>
<td>3, 5, 8, 11, 13, 20, 35, 36, 39, 49, 57, 89, 98, 109, 121, 124, 125, 130</td>
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<tr>
<td><strong>Affairs</strong></td>
<td>122</td>
</tr>
<tr>
<td><strong>Asking of Questions</strong></td>
<td>44</td>
</tr>
<tr>
<td><strong>Attempt</strong></td>
<td>5, 10, 103</td>
</tr>
<tr>
<td><strong>Basic Research</strong></td>
<td>68</td>
</tr>
<tr>
<td><strong>Behaviour</strong></td>
<td>67, 73</td>
</tr>
<tr>
<td><strong>Clarification of Problems</strong></td>
<td>44</td>
</tr>
<tr>
<td><strong>Combination of Methods, Knowledge and Values</strong></td>
<td>30</td>
</tr>
<tr>
<td><strong>Contention</strong></td>
<td>83</td>
</tr>
<tr>
<td><strong>Creation</strong></td>
<td>15</td>
</tr>
<tr>
<td><strong>Criticism</strong></td>
<td>117</td>
</tr>
<tr>
<td><strong>Decision(s)</strong></td>
<td>61, 116</td>
</tr>
<tr>
<td><strong>Description</strong></td>
<td>121</td>
</tr>
<tr>
<td><strong>Developments</strong></td>
<td>102, 123</td>
</tr>
<tr>
<td><strong>Developing Statements</strong></td>
<td>59</td>
</tr>
<tr>
<td><strong>Discourse</strong></td>
<td>88, 106</td>
</tr>
<tr>
<td><strong>Discoveries/Discovery</strong></td>
<td>84, 122</td>
</tr>
<tr>
<td><strong>Efforts</strong></td>
<td>103</td>
</tr>
<tr>
<td><strong>Endeavour</strong></td>
<td>116, 127</td>
</tr>
<tr>
<td><strong>Enterprise</strong></td>
<td>19, 27, 36, 85, 87, 131</td>
</tr>
<tr>
<td><strong>Explanation</strong></td>
<td>8, 42</td>
</tr>
<tr>
<td><strong>Fruct of Investigation</strong></td>
<td>37</td>
</tr>
<tr>
<td><strong>Growth</strong></td>
<td>110, 111</td>
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<tr>
<td><strong>Innovative</strong></td>
<td>76, 111</td>
</tr>
<tr>
<td><strong>Intellectual Enterprise</strong></td>
<td>47</td>
</tr>
<tr>
<td><strong>Inquiry</strong></td>
<td>94, 129</td>
</tr>
<tr>
<td><strong>Investigation</strong></td>
<td>80</td>
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<tr>
<td><strong>Making</strong></td>
<td>121</td>
</tr>
<tr>
<td><strong>Means</strong></td>
<td>122, 122</td>
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<tr>
<td><strong>Method(s)</strong></td>
<td>24, 26, 29, 30, 38, 52, 58, 97, 103, 103, 105, 105, 125</td>
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<tr>
<td><strong>Methodology</strong></td>
<td>50, 122</td>
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<tr>
<td><strong>No Scientific Method</strong></td>
<td>96</td>
</tr>
<tr>
<td><strong>Observations</strong></td>
<td>121</td>
</tr>
<tr>
<td><strong>Planning</strong></td>
<td>74</td>
</tr>
<tr>
<td><strong>Practice</strong></td>
<td>53, 106, 116, 131</td>
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<tr>
<td><strong>Problem-solving</strong></td>
<td>59</td>
</tr>
<tr>
<td><strong>Procedure(s)</strong></td>
<td>14, 63, 120</td>
</tr>
<tr>
<td><strong>Process(es)</strong></td>
<td>4, 34, 105, 123</td>
</tr>
<tr>
<td><strong>Production</strong></td>
<td>24</td>
</tr>
<tr>
<td><strong>Progress</strong></td>
<td>86</td>
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<tr>
<td><strong>Pursuit</strong></td>
<td>110</td>
</tr>
<tr>
<td><strong>Quest</strong></td>
<td>103</td>
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<tr>
<td><strong>Research</strong></td>
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<tr>
<td><strong>[Scholarship]</strong></td>
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<tr>
<td><strong>Scientific Method</strong></td>
<td>82, 95</td>
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<tr>
<td><strong>Search</strong></td>
<td>9, 85, 124</td>
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<tr>
<td><strong>Skill</strong></td>
<td>1, 80</td>
</tr>
<tr>
<td><strong>Study</strong></td>
<td>1, 21, 46, 80</td>
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<tr>
<td><strong>Technique</strong></td>
<td>23</td>
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<tr>
<td><strong>Type of Argument</strong></td>
<td>103</td>
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<tr>
<td><strong>Ways of Thinking/Thinking/Thought</strong></td>
<td>14, 97, 105</td>
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<tr>
<td><strong>Work</strong></td>
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Table A.5
Classes of subjects from Table A.2 which indicate that science is characterised by intention, purpose or goal

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<td>GOAL(S)/OBJECTIVES</td>
<td>5, 35, 20, 85, 88</td>
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<td>MAIN BUSINESS</td>
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<td>[PLANNING]</td>
<td>74</td>
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<td>STRATEGIES/STRATEGY</td>
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### Table A.6

Classes of subjects from Table A.2 which indicate that science is characterised by context

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<td>Community of Individuals</td>
<td>33</td>
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<td>Context</td>
<td>24</td>
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<tr>
<td>Cultural Artefact</td>
<td>79</td>
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<tr>
<td>Culture</td>
<td>51, 126</td>
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<td>Entrenched</td>
<td>25</td>
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<tr>
<td>Linked with Politics</td>
<td>56</td>
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<tr>
<td>Monopolistic</td>
<td>89</td>
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<tr>
<td>Natural and Physical Science</td>
<td>80</td>
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<tr>
<td>Occupation</td>
<td>80</td>
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<tr>
<td>Other Characteristics</td>
<td>42</td>
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<td>Papers</td>
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<td>Place in Society at Large</td>
<td>88</td>
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<tr>
<td>Product</td>
<td>122</td>
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<td>Profession</td>
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<td>Resource</td>
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<td>Scientific Community</td>
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<td>Society</td>
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<td>Sub-Culture</td>
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<td>Tradition</td>
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<td>Unique</td>
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Table A.7
Classes of subjects from Table A.2 which indicate that science is characterised by structure, system, relation or syntax

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<td>INDUSTRIES</td>
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<td>MATHEMATICAL FORMULATION</td>
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Table A.8
Classes of subjects from Table A.2 which indicate that science is characterised by some sort of subconscious mind-set, including beliefs, attitudes, values, criteria for judgements, disposition, assumptions

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<td>Commitment</td>
<td>5, 29, 61</td>
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<td>Criteria</td>
<td>47, 123</td>
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<td>Criteria of Judgement</td>
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<td>Dealing only with the world of appearance</td>
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<td>Disposition</td>
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<tr>
<td>Exactitude</td>
<td>121</td>
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<tr>
<td>Fundamental Conceptions</td>
<td>61</td>
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<tr>
<td>Generality</td>
<td>42</td>
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<tr>
<td>Idea of Hidden Order in Nature</td>
<td>86</td>
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<td>Ideology</td>
<td>14</td>
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<tr>
<td>Intolerant</td>
<td>76</td>
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<tr>
<td>Merciless</td>
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<td>[Not clearly distinguishable from philosophy]</td>
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<tr>
<td>Not magical</td>
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<td>25, 27</td>
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<td>Ontology</td>
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<td>Picture</td>
<td>105</td>
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<td>[Philosophical] Support/Aspects</td>
<td>25, 99</td>
</tr>
<tr>
<td>Philosophy</td>
<td>80</td>
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<td>Precision</td>
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<td>Rationality</td>
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<td>Roots</td>
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<td>Rules</td>
<td>54, 63, 103</td>
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<td>Scientific Mind</td>
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<td>Simplicity</td>
<td>42</td>
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<td>Taken for granted</td>
<td>25</td>
</tr>
<tr>
<td>Type of thinking</td>
<td>87</td>
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<tr>
<td>Values/mores/value posture</td>
<td>30, 31</td>
</tr>
<tr>
<td>Vision</td>
<td>61</td>
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<tr>
<td>Wisdom</td>
<td>25</td>
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<td>World/world picture/world view</td>
<td>16, 73, 74, 92, 110, 128</td>
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## Table A.9
Categorisation of the Differentiae in Table A.1 by the categories of classes identified in Tables A.3 to A.8

<table>
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<th>No. from Fig. A1</th>
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<th>Active</th>
<th>Structural</th>
<th>Purposive</th>
<th>Contextual</th>
<th>Foundational</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>• conceptual understanding • natural world</td>
<td>• deductions and inferences • formulated • observations and measurements • of humanity • [of human] environment • of events and parameters within the universe</td>
<td>• systematic • general laws • systematic • branch of [knowledge]</td>
<td></td>
<td></td>
<td>• reproducible</td>
</tr>
<tr>
<td>2</td>
<td>• extend ...and reduce [experience]</td>
<td></td>
<td>• order</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>• understanding • world around us</td>
<td>• exploratory • come to</td>
<td></td>
<td>• purpose</td>
<td></td>
<td></td>
</tr>
<tr>
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| 25  | - habitual                           | - standard view | - underlying |
|     |                                     | - shared by    | - ideal of |
|     |                                     | - reflective   | - responsibility |
|     |                                     | - scientists,  | - belief |
|     |                                     | - technical    | - against |
|     |                                     | - philosophers,| - wilfulness, |
|     |                                     | - and the      | - authoritarian- |
|     |                                     | - educated     | - ism, and |
|     |                                     | - public       | - inertia |
|     |                                     | - of our day   |            |
|     |                                     | - dominant     |            |
|     |                                     | - [and]        |            |
|     |                                     | - scientifically oriented |            |

| 26  | - method                             | - end         | - standard view          |
|     | - reality                            |              | - objectivity            |
|     |                                     |              | - ontological            |
|     |                                     |              | - vision                 |
|     |                                     |              | - objectivity            |
|     |                                     |              | - beginning              |
|     |                                     |              | - universe of            |
|     |                                     |              | - objects with           |
|     |                                     |              | - independent            |
|     |                                     |              | - existences and         |
|     |                                     |              | - careers                |

| 27  | - facts                               | - systematic  | - purpose                |
|     |                                       | - expressed in | - [standard] view         |
|     |                                       | - laws        | - public                 |
|     |                                       | - lawlike      |                         |
|     |                                       | - hypotheses   |                         |
|     |                                       | - of nature    |                         |

| 28  | - discover                            | - in the standard view | - truths               |
|     |                                       |                         | - external world       |
| 29 | • knowledge | • evaluating data | • for what we are looking for and what we are trying to accomplish | • human | • logic and rationality | • value-oriented |
| 30 | • knowledge | • is certified | • characteristic | • cultural | • governing [scientific] activities |
| 31 | • judgement and expectation | • roles | • relativistic | • societal | • rationalistic | • anticipates change |
| 32 | • extended and refined | • perception | • judgement and expectation | • institutional structures | • pragmatic | [rather than ritualistic] |
| 33 | • activities of inquiry | • intent | • of the same order as that of ordinary | • sometimes | • value | • values |
| 34 | • misunderstanding of knowledge | • active | • similar and related | • like any other group of people | • must ... have a philosophy |
| 35 | • understanding | • prediction and control | • through the ages | • in our own age | • valid and successful |
| 36 | • concepts | • correlation | • goals | • which set [science] apart from other human activities | • causal connections |
| 37 | • subject matter | • application of logic | • arrangements | • subject | • false |
| 38 | • knowledge | • acquire | • set ... within a more comprehensive | • appropriate |

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<td>- [what ... the world is like]</td>
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<td>- whether natural ... or artificial</td>
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<td>discovery or uncovering</td>
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<td>52</td>
<td>experimental mathematical mathematical union of processes of the natural world behaviour of nature</td>
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<td>53</td>
<td>discovering by examination of evidence not through coercion, personal argument or appeal to authority seeks answers seeks answers</td>
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<td>54</td>
<td>[knowledge]</td>
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<td>55</td>
<td>knowledge informing arranging highly organised through appropriate organisation combined</td>
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<td>57</td>
<td>phenomenon interaction latched onto with the environment regularities in nature biological by one kind of organism</td>
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<td>Cognitive</td>
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<td>61</td>
<td>• knowledge</td>
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- Cognitive
- Epistemic
- Explanatory Principles
- Cognitive
- Theory Testing and Selection
- Intervene
- Modify
- Explanations
- Common Set of Theories
- Various Components
- Goals
- To Acquire Predictive Control
- To Acquire Manipulative Control
- So as to be Able to
- To Increase the Precision of the Parameters
- To Integrate and Simplify Aims
- Over ... Parts of One's Experience
- Better than ... 'Non-Scientific'
- Pragmatic
- Initial and Boundary Conditions
- Our Picture
- Reliable
- Efficient
| 62 | natural events | [on Kant's account] of a problem as distinct from a doctrine of knowledge and of the object of that knowledge of natural science and of nature one existing world a world of exclusively self-consistent and discoverable rational causality of nature natural events |
| 63 | amended thinking | [by philosophy] scientific conclusions that would be acceptable based on some metaphysical dogma ... that is usually unexamined seems self evident |
| 64 | delicate manipulations use of the hands | originality curiosity desire to generalise intelligence perseverance the finding of pleasure |
| 65 | knowledge of knowledge of [valid] ideas acquire approved approval | by all sane men only the sane men who have studied it give their [approval] the relations between the phenomena which make themselves known to us or which we apprehend by means of our senses valid understatement of the feelings of men towards feelings |
| 66 | *not a mere repetition* |
| 67 | *acquires mastery* |
|     | *of the environment* |
| 68 | *knowledge* |
|     | *of the natural world* |
|     | *of how we can use [that knowledge]* |
| 69 | *knowledge* |
|     | *knowledge* |
|     | *information and understanding* |

| 66 | |
| 67 | *to serve as an end in itself* |
|     | *to form a basis for technology* |
|     | *[on Crowther's account]* |

| 68 | *aimed for the sake of advancing that knowledge* |
|     | *to provide the background* |
|     | *recognised current or future practical problems* |

| 69 | *advancement* |
|     | *produce* |
|     | *solution of* |
|     | *research* |
|     | *advancing [knowledge]* |
|     | *solution of* |
|     | *discovery* |
|     | *development* |
|     | *application* |
|     | *used* |
|     | *rearrangement* |
|     | *whole matrix* |
|     | *without the goals* |
|     | *strategic objectives* |
|     | *to [produce] a broad base [of knowledge]* |
|     | *for the [solution of]* |
|     | *to solve problems* |
|     | *basic* |
|     | *long term economic or social benefits* |
|     | *practical problems* |
|     | *recognised current or future practical problems* |
|     | *long-standing separation of scientific and industrial research in Australia* |
|     | *occasional examples* |
|     | *contributes to an international matrix* |
|     | *international* |
|     | *in a particular application* |
|     | *immediate* |
|     | *an industrial problem* |
|     | *expectation* |
70

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- [not] concerned with ... man, culture and society
- physical, chemical, biological, earth, engineering and applied, and agriculture
| 71 | research | research | change their view of | following | research | exploration | discovery | should be left [to scientists] to do it | new laws | aims of their research | the goals [of society] | investment should show some return which will tangibly benefit the country | research managers | sustained funding | managers | researchers | well developed international reputation | a particular line of | related to reasons outside of their narrow discipline | (in Australia, 1989) | the ripeness of the area | potential | broad scientific applicability | attractiveness of the area to the most able scientists | potential | stimulation of other sciences | the potential contribution to ... engineering, medicine, applied science; technology; immediate applications; prestige and international cooperation; [the goals] of society; national responsibilities; public education. | trust | reasons for | significance of the questions addressed | fundamental |
| 72 | understanding | application of method | mathematical hypotheses systems | Western Europe at the time of Galileo in the late Renaissance | primary and secondary qualities |
|    |              | geometrication |                        | modern type primitive or mediaeval type | acceptance intrinsic and essential |
|    |              | numbers ... employed |                        | a posteriori a priori | [precision] |
|    |              | qualitative measurements |                        |                      | [capable] of |
|    |              | compared [not manipulated constructed proof or disproof combine |                      |                      | [not] prone to |
|    |              | of space |                        |                      | fanciful |
|    |              | to Nature |                        |                      | of gnostic correlation |
|    |              | * on how to live and how to look | making plans formula | species-specific human | * of the mechanical model of reality |
| 73 | understanding | activity | not ... by ... formula | not ... independent, value-free, dissociated | based on the notion |
|    |              | attack |                        | [cannot] be carried on apart from the rest of human life | refuses to acknowledge a division between two kinds of logic |
|    |              | apply the logic |                        | long-term | active view of how |
|    |              |            |                        | no distinction [from] human strategies | one form of truth |
|    |              |            |                        | distinguished from magical views | no distinction between man and nature |
|    |              |            |                        | works the same way in all forms of conduct | no distinction between the logic of magic and other logics |
|    |              |            |                        | long-term | no distinction between means and ends |
|    |              |            |                        | to the conduct of the whole of your life | distinguished from earlier forms |
|    |              |            |                        | distinguished from earlier forms | |
| 74 | knowledge | activity | cannot [separate] life [into] scientific [and not, or] nature [and] man [or] means [and] ends | directed toward planned action [humans] guide their conduct by looking ahead and making choices | cannot make a distinction between power and knowledge |
|    |              | active |                        | [not] ... isolated or independent general human approach | |
|    |              |            |                        |                      | |
| 75 | • derived  
   • [to] refer to the general rule to determine the stance he should take  
   • adjustments  
   • vary greatly | • not simply [a] collection [of norms]  
   • structure [of norms]  
   • relationship to each other  
   • interrelatedness  
   • systematic  
   • tightly linked general statements  
   • specific propositions  
   • high degree of system | • vary greatly  
   • [when] confronted by a new situation  
   • the believer | • norms  
   • norms  
   • substantive beliefs |
| 77 | • the ability to ... relate propositions  
   • can be reconstructed and perpetuated  
   • experiment  
   • applied | • systematically  
   • according to an [internally] consistent logic | • internally]  
   • any social group  
   • by anyone who knows it | • validation comes from empirical events  
   • logic |
| 78 | • facts  
   • discovered and tested  
   • scientific method  
   • solving problems | • broad field  
   • held together by principles (rules)  
   • orderly system  
   • mathematics and logic  
   • physical sciences  
   • biological sciences  
   • social sciences | • human | |
| 79 | • created | • a different society, with a different 'cultural hypothesis'  
   • in a sense | |
| 80 | • facts  
   • [from] study  
   • observed  
   • methods  
   • study  
   • of something | • branch of  
   • connected body  
   • systematically classified  
   • colligated by being brought under general laws | • for the discovery of new truths  
   • of any field  
   • within its own domain  
   • one of many kinds  
   • as distinguished from other departments of learning [in modern use] | • of something  
   • of demonstrated truths  
   • trustworthy |
| 81 | | • human, social, political  
   • with complicated histories and relations to the rest of society | |
| 82 | facts | thinking | a set of | 2500 year old story |
|    | facts | observe and report | system | have always |
|    | knowledge | by tests | theories are generalisations | Western |
|    |          | makes progress | makes progress | humans |
|          | confirmed by tests |          | no social, personal or political bias | makes progress |
|          |          |          | sole basis for technology and social progress | confirmed by tests |
|          |          |          | makes progress | based on assumptions |
|          |          |          | makes progress | objective |
|          |          |          | makes progress | objectively |
|          |          |          | makes progress | based on facts alone |
|          |          |          | makes progress | true or 'confirmed' |
|          |          |          | makes progress | proven |
|          |          |          | makes progress | true |
|          |          |          | makes progress | True Nature |
|          |          |          | makes progress | about Nature |
|          |          |          | makes progress | messy, complex |
| 83 | scientific method |          | cultural | ideological forces |
|    | seething |          | human | |
|    |          |          | historical | |
|    |          |          | shaped by | |
|    |          |          | cultural, economic | |
|    |          |          | forces | |
|    |          |          | social-political | |
| 84 | certain changes | structure | human plans | human ideas |
|    | certain specified material practices | linkages | existing | belief |
|    | have to do with [human] interaction | theory | human | human ideas |
|    | imposing of grids |          | human | theories |
|    | change of |          | cultural | |
|    | associated with certain actions |          | human | |
|    | practical implementation |          | cultural | |
|    | like new product lines |          | human | |
|    | **with nature** |          | human | |
|    | **on nature** |          | human | |
|    | **things in the world** |          | human | |
| 85 | production | algorithmic compressions | by human beings | the logic |
|    | [not] indiscriminate accumulation of every available fact | abbreviated | |
|    | representation | unifying principles we call laws | |
|    | written down | algorithmically compressible | |
|    | description | abbreviated | |
|    | **of the world** | in finite form | |
|    |          | **of observational data** | |
|    |          |          | |
|    |          |          | *the Universe*
<p>|    |          |          | <em>behind the Universe's properties</em> |</p>
<table>
<thead>
<tr>
<th>86</th>
<th>• could be uncovered by ingenious investigation • measurement</th>
<th>• both reductionistic and holistic • mathematical in form • abstract theoretical framework • systematic</th>
<th>• special</th>
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<tr>
<td>87</td>
<td>• observe</td>
<td>• to be able to work out its form and content</td>
<td>• we need not actually • things are as they are as a result of some sort of logical necessity • mostly [without] God • world forms a closed and complete system of explanation • assumption • rational and intelligible • principle of sufficient reason • based upon the assumed rationality • the world • of nature</td>
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| 88   | • findings
      |          |          |          |
|      | • product of ... enterprise
      |          |          |          |
|      | • purified, extended
      |          |          |          |
|      | • mutual criticism
      |          |          |          |
|      | • intellectual cooperation
      |          |          |          |
|      | • are educated
      |          |          |          |
|      | • choose research topics
      |          |          |          |
|      | • communicate
      |          |          |          |
|      | • criticise and refine
      |          |          |          |
|      | • relate
      |          |          |          |
|      | • research and development
      |          |          |          |
|      | • research
      |          |          |          |
| 89   | • self-critical
      |          |          |          |
|      |          |          |          |          |
|      |          |          |          |          |
| 90   | • communicating, criticising and socially-interacting observers
      |          |          |          |
|      |          |          |          |          |
|      | • system
<p>| | | |
|          |          |          |
|      |          |          |          |          |
|      |          |          |          |          |
|      |          |          |          |          |
|      |          |          |          |          |
| 91 | • stored and communicated | • formalised languages | • more or less artificial | • reproducible | • material maps |
|    |                           | • language            | • public noetic domain   |              |                |
|    |                           |                      | • private mental domain |              |                |
|    |                           |                      | • each individual       |              |                |
|    |                           |                      | • natural [language]    |              |                |
|    |                           |                      | • particular social group |            |                |
| 92 | • conceptual              | • subscribe          | • one of many [attendant metaphorical interpretations] | • according to principles of the sociology of knowledge |
|    |                           | • systematic scheme  | • noetic domain         | • revelations |
|    |                           | • schematised         | • not privileged by     | • foundations |
|    |                           | • theoretical        | comparison with any     | • not necessarily true |
|    |                           | • consequences       | other                   | • errors and fallacies |
|    |                           |                      | • a social group        |                |
|    |                           |                      | • contrast ... with     |                |
|    |                           |                      | alternative nonscientific world pictures |    |
|    |                           |                      | • modern                |                |
|    |                           |                      | • mundane               |                |
|    |                           |                      | • consensual            |                |
|    |                           |                      | • extreme               |                |
|    |                           |                      |                         |                |
| 93 | • creation                |                      | • consensus             | • based on ... a pre-existing mental harmony |
|    |                           |                      | • public domain         |                |
|    |                           |                      | • between independent human beings |            |
|    |                           |                      | • matters of common interest |        |
| 94 | • observational procedures| • patterns of [argument] |                        | • metaphysical presuppositions |
|    | • argument               |                          |                          | • validity |
|    | • methods of representation and calculation |                          |                          | • from formal logic |
|    | • analysed and discussed |                          |                          | • metaphysics |
|    | • practical methodology |                          |                          |                |
| 95 |                           | • a definite pattern   |                          |                |
| 97 | • based on particular methods of inquiry and thinking | • systematic and formulated | • attitudes |
|    | • critical appraisal     | • mixture of theoretical and practical | • open-mindedness and impartiality |
|    | • ways of thinking       | • theoretical models and explanations | • respect for data |
|    | • explain                |                          | • tentativeness about accepting results as final |
|    | • development            |                          | • disciplined approach  |                |</p>
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<th>98</th>
<th><em>verification</em></th>
<th><em>wide variety</em></th>
<th><em>natural phenomena</em></th>
<th><em>natural phenomena</em></th>
<th><em>intellectual</em></th>
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<td>[since] nineteenth century</td>
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<td>100</td>
<td><em>discourse</em></td>
<td><em>statement</em></td>
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<td><em>would only count as science if</em></td>
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<td><em>confirmable empirical</em></td>
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<td>101</td>
<td><em>process or program of empirical, explanatory inquiry</em></td>
<td><em>characteristic structures</em></td>
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<td><em>structures that constitute physical theories</em></td>
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<td>102</td>
<td>cognitive or conceptual knowledge</td>
<td>research [cognitive] developments being shaped by institutional developments</td>
<td>new directions new fields institutional cognitive ... institutional scientific labour inside the laboratory interdisciplinary research teams trans-laboratory networks the basic-applied dichotomy of the past to [distinguish] in practice than in the past commercial exploitation necessary for the survival of firms in certain industrial sectors of the economy new manufacturing processes and products of the twenty-first century bioscience, information technology and new material sciences by national and international agencies</td>
<td>[research] is less easily divided less easy to distinguish</td>
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<td>103</td>
<td>• meaning</td>
<td>• establish [relationships]</td>
<td>• to discover facts</td>
<td>• ever-unfinished</td>
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<td>• understand</td>
<td>• interpret</td>
<td>• consistent structure with order [and meaning]</td>
<td>• our most persistent intellectual</td>
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<td></td>
<td>• conceptual</td>
<td>• transcend</td>
<td>• of pattern, order, system, structure</td>
<td>• as in art and philosophy</td>
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<td>• discovery</td>
<td>• cosmological synthesis</td>
<td>• one facet</td>
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<td>• discernment</td>
<td>• sequence</td>
<td>• [which separate] the sciences from the nonsciences</td>
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<td>• intellectual adventure</td>
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<td>• the scientist</td>
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<td>• uses</td>
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<td>• the world of experience</td>
<td>• accumulate</td>
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<td>• internationally [acceptable]</td>
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<td>• innovation and revolutions</td>
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<td>• fairly enduring</td>
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<td>• many methods and unaccountable variants</td>
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<td>• read into the story</td>
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<td>• actual working procedures</td>
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<td>• have actually done their work</td>
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| 125 | activity | set | aims | scientists | rational |
|     | explanations | statements | aim | | satisfactory |
|     | describes | | | | causal |
|     | explained | | | | |

| 126 | concepts and words | framed | theoretical | scientific findings | relevant and momentous |
|     |                    | musing | constructs | cultural context | world picture |
|     |                    | understood | | educated community | |
|     |                    | atrophy and ossify | | the initiated | |
|     |                    | | | each other | |
|     |                    | | | small group of close fellow travellers | |
|     |                    | | | cultural mankind | |
|     |                    | | | within its ... isolated groups of experts | |
|     |                    | | | | |

*material substances about the world of what it is to understand*
| 127 | ideas *understanding about the physical, biological, psychological, and social worlds of the human species and its environment | developed *achieve *observing *thinking *experimenting *validating *knowing *validated | interconnected *enterprises | human history *people *successive generations *comprehensive *mathematics and technology *human *character and history of its own | reliable |
| 128 | knowledge | working *discussing *do science *work *working *figure out *studying *stable *subject to change | scientists *a lot of time *nonscientists *over time *applied | belief |
| 129 | process *making *observations *organising *the scientific method *doing experiments *inquiry *working *make great discoveries | complex *flexible *rigid *sequence of steps | laboratories *individual investigators *enterprise as a whole | imagination and inventiveness *logic *logical and empirical evidence |
| 130 | endeavour *learning | for [learning] | contemporary world *present times *earlier periods *people |
| 131 | | intertwined | mathematics *technology |
Sc defn anal Tables A1-9

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Table A.10
Comparison of categories of characterisation
between the classes and differentiae
Categories of characterisation in the differentiae in Table A.l
Categories Knowledge Activity
Context
Structure
Purpose
of
characterisation in
classes
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ACTIVITY

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Appendix B.1

Argument from the metascientific literature emphasising the dimension context

Debates in the metascientific literature address many aspects of context in science, which again supports a broad interpretation of scientific context. Appendix B.1 outlines the variations, implications and subtleties of several of these debates to indicate the scope of the ways in which science is characterised partly by context:

B.1.1 Current metascientific views with respect to context;
B.1.2 Boundary concerns;
B.1.3 Context as being ‘Internal’ and ‘External’;
B.1.4 Historical contexts of science;
B.1.5 Intellectual contexts of science;
B.1.6 Socio-cultural contexts of science;
B.1.7 Human contexts of science;
B.1.8 Organisational contexts; and
B.1.9 Physical contexts of science.

This is not intended as an exhaustive list, but merely one which addresses significant themes in characterisations of science in the literature.

1.1 Current metascientific views with respect to context

The range of contemporary metascientific views, from HPS, STS and other fields, makes stronger appeals to context than does the Received View that they challenge. Table B.1.1 indicates this range by presenting differing conceptions of context in metascientific views. Boyd, Gasper and Trout (1991) list three views that comprise a current consensus in HPS, in which context is taken to be: (a) intellectual or cognitive only, where scientific knowledge is taken as given in sense experience (empiricism); (b) intellectual and psychological, and in some versions also socio-cultural, where scientific knowledge is taken as what is constructed (constructivism); and (c) intellectual, psychological, socio-cultural and ontological, where scientific knowledge is taken to arise from the human investigation of an external and independently existing reality (scientific realism).

In his overview of STS approaches, Callon (1995) has identified four main views of science. Where science is characterised as (a) rational knowledge, the distinguishing characteristics are the cognitive and discursive contexts given in statements and networks of statements. Callon sees this as paradoxical with respect to context, because the generation and testing of statements can only take place within contexts that are protected by institutions and society generally.
Without the public space of (free) discussion, science degenerates into beliefs stamped with subjectivity. Science is synonymous with democracy or, to use Popper's (1945) expression, open society. In an open society, institutions are the revisable creations of human activity; the critical mind knows no limits - gods, Caesars, or tribunes. Questioning is permanently renewed and no state of rest is satisfactory. The individual is privileged because she [sic] both introduces and judges novelty. There is an analogous concern in the writing of Habermas (1987) with pressing science into a space for public discussion and communication. (Callon 1995, p. 35)

Thus the primary notion of context is intellectual or cognitive, but this seems to entail broader, socio-political contexts that are not resolved or even clarified in these characterisations.

Where science is characterised as (b) a competitive enterprise, there is a clear notion of scientific context being the scientists (specialists) themselves, who interact and compete, and who are contextually quite separate from lay audiences who are not qualified to take part in these activities. It is the scientific community who interact socially and internally to reward discoveries or contributions, using 'material devices and rules that codify the formulation of knowledge and its transmission' (Callon 1995, p. 39), and provide the context for free discussion and allocation of resources. The boundary between science and its environment is clear, and marks the distinction between where the rules, incentives and resources apply or not, although it 'must be sufficiently permeable to transmit the influences that nourish science and ensure its social utility' (Callon 1995, p. 41).

Where science is characterised as (c) sociocultural practice, scientific activities and outcomes are characterised as much more than the simple generation and translation of statements, and the activities of science are presumed to have no greater status or privilege than those of other institutions:

The third model suggests that science must be considered to be a practice whose cultural and social components are as important as the constraints that arise from the order of discourse. (Callon 1995, p. 42)

Callon again finds this a paradoxical stance with respect to context, because it is 'only moderately interested in questions of organisation and institutional forms. This observation applies as much to the internal organisation of scientific activity as to its relations with the sociopolitical environment' (Callon 1995, p. 48). It is more concerned with issues like rules, learning and boundaries, which include social and psychological contexts, rather than with organisations per se.

Finally, where science is characterised as (d) extended translation, context is interpreted as the interactions between actants - humans, technical devices and statements - that are described as translation networks (Callon 1995, pp. 50ff). This suggests that the traditional distinction between Nature and society is outdated. Studies that characterise
science by translation networks include the growing genre of laboratory studies, that take the laboratory as the primary contextual element.

Insofar as Boyd, et al, and Callon provide reasonable sketches of the fields of HPS and STS, respectively, clearly there are significant differences about context both within and between fields. There are also some similarities: the notion of cultures or interests as contexts for science, for example, is common in STS characterisations and consistent with HPS positions such as constructivist characterisations and scientific realism (see, for example, Chalmers 1976; Bhaskar 1983k). These debates about particular notions of context are all examples of the general notion of context as a dimension of science, which is used regardless of the metascientific tradition. The remainder of Appendix B.1 comprises examples to support this claim.
1.2 Boundary concerns

All fields, including science, are characterised by boundaries that are established between what is agreed as the field (in this case science) and what is not. This may be seen as part of a broader interest in so-called boundary work:

No doubt, speech about the intrinsic and the extrinsic is characteristic of a wide range of cultural practices and arguably of all. Bounding a practice is a way of defining what it is, of protecting it from unwanted interference and excluding unwanted participants, of telling practitioners how it is proper to behave within it and how that behaviour differs from ordinary conduct, and of distributing value across its borders. Practices that have not succeeded in making their boundary-discourse stick are unlikely to be recognisable as distinct entities within the general stream of cultural life. (Shapin 1992, p. 335)

Boundary work draws on a wide range of characterisations emphasising context and other dimensions. It comprises characterisations of sufficient clarity to enable claims about what is (inside the boundary of) science and what is not. Boundary claims may be explicit or implicit. For example, the view that knowledge in the natural sciences arises from the nature of the cosmos implies a boundary indicating science from non-science: science is therefore different from other forms of knowledge, which are socially constructed. This view is of course consistent with the positivist RV in HPS, but is also well known from the work of the sociologist Karl Mannheim (1929, 1936). Mannheim considered that the sociology of knowledge applied to all forms of knowledge except science, which was determined by an objective reality. Shapin notes a tendency for internalist accounts to be normative, and for externalist accounts to be descriptive, particularly in historical and sociological analyses; philosophical analyses have not seriously addressed science and its context until recently. The first clear use of the e/i distinction probably was given in Merton (1938) and more recent uses include Foucault’s analysis of the creation and manipulation of power in society:

Much Foucauldian work sees patterns of exclusion and inclusion, of ‘controlling and delimiting discourse’, as systems making truth and power. (Shapin 1992, p. 335)

Boundaries as essential or constructed

Given this preamble, it is clear that a great number of the very many metascientific accounts entail boundaries between science and non-science, whether explicitly or implicitly. There are two broad approaches to boundary work, essentialism and constructivism:

Essentialists argue for the possibility and analytic desirability of identifying unique, necessary, and invariant qualities that set science apart from other cultural practices and products, and that explain its singular achievements (valid and reliable claims about the external world). Constructivists argue that no demarcation principles work universally and that the separation of science from
other knowledge-producing activities is instead a contextually contingent and interests-driven pragmatic accomplishment drawing selectively on inconsistent and ambiguous attributes. Research in the sociology of science has raised doubts about the ability of any proposed 'demarcation criteria' to distinguish science from non-science. Attention has thus shifted from criticisms of essentialism to examinations of when, how, and to what ends the boundaries of science are drawn and defended in natural settings often distant from laboratories and professional journals - a process known as 'boundary-work'. Essentialists do boundary-work; constructivists watch it get done by people in society - as scientists, would-be scientists, science critics, journalists, bureaucrats, lawyers, and other interested parties accomplish the demarcation of science from non-science. (Gieryn 1995, pp. 393-4)\(^1\)

### Essentialist views of science boundaries

The major essentialist positions in boundary work have been given in philosophy by Popper, in history by Kuhn and in sociology by Merton (Gieryn 1995, pp. 394ff). The essentialist criterion for Popper is falsifiability: that scientific claims can in principle be refuted or contradicted by empirical observation. This can be done in any of three ways: if the claim is judged to be potentially unfalsifiable, if no severe test is made to refute the claim, or if the claim is not rejected after being refuted, representing respectively a belief, a practice and 'adherence into non-science' (Gieryn 1995, p. 396). For Popper, non-science includes metaphysics, ideology, pseudoscience, mathematics, logic, Marxism, astrology and Freudian psychoanalysis. For Merton the essentialist criteria are his four social norms of science: communism, universalism, disinterestedness and organised scepticism. For Merton, non-science is characterised by the absence of any of these norms. An example is ideology, such as racist assertions in Nazi Germany, because it has interested and not disinterested purposes. Kuhn’s account does have constructivist characteristics: Popper dismissed Kuhn ‘as a historical relativist and (worse) one who would allow the sociology and psychology of science to settle issues (like demarcation) that are more properly settled by logic and methodology’ (Gieryn 1995, p. 401). However, Gieryn interprets paradigmatic consensus as an essentialist demarcation principle in Kuhn’s characterisation. Thus the absence of paradigmatic consensus in the social sciences dooms those fields to incessant argument about ideology and first principles, that precludes the coherent progress characteristic of the mature physical sciences. Intriguingly, Gieryn mentions Kuhn’s rejection of astrology as unscientific because it has ‘no puzzles to solve and therefore no science to practice’ (Kuhn 1977, quoted by Gieryn 1995, p. 403), but fails to identify puzzle solving or problem-solving as a demarcation principle. Elsewhere Kuhn identifies ‘the normal

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\(^1\) Gieryn’s account clearly identifies the present thesis as a constructivist example of boundary work, because by definition a 'mapping' exercise like this thesis cannot presume the efficacy of any single view. This thesis does not set out its own boundary for 'science', but seeks to address the variation of views of science in order to inform the debate about what could or should be presented in schools as 'science'.
puzzle-solving research of the natural sciences’ as a principle of demarcation from the human sciences, which he sees as fundamentally interpretive or hermeneutic (Kuhn 1991, pp. 22-3).

There are problems with essentialist accounts of demarcation. For example, the falsificationist can never be sure when an empirical claim is replicated or corroborated:

Collins argues that there is no unambiguous and impersonal algorithm for reproducing an experimental procedure. Scientists routinely face the problem of deciding when a replication is competent and authentic. ‘Experimenter’s regress’ is a paradox for those like Popper who want to ‘use replication as a test of the truth (falsification) of scientific knowledge claims’ [Collins 1985] because negotiation of the competence of a replication attempt is, at once, negotiation of the reality of phenomena at hand. In his study of gravity wave experiments, Collins reports that scientists’ judgements about the competence of a replication experiment hinged on whether the results of that experiment were consistent with their theoretical assumptions going in. This research challenges an inherent part of Popper’s demarcation criteria, for how can refutation or falsification occur if scientists sometimes exploit available rhetoric (human error, machine failure, extraneous circumstances, technical infelicity) to neutralise potentially falsifying observations by attributing them to incompetent or unauthentic replications? (Gieryn 1995, pp. 397-8)

A similar problem arises with Mertonian norms, which take ‘the supposed essential qualities of science - those that distinguish it from non-science - and makes them into matters for people in society to construct, interpret, negotiate, and deploy’ (Gieryn 1995, p. 400). As for Kuhn’s paradigmatic consensus, the paradigm itself is socially constructed, which fails to address discrepancies between the beliefs - especially any misgivings - held by the individual scientist, and the consensus view. Further, identifying the consensus has particular problems: first is the problem of deciding the limits of the membership of the research community who proclaim a consensus (who excludes the dissenters?); second are the judgements about the beliefs of other scientists (who accepts the new belief and when did they decide?); and third is the decision about just what is agreed upon. Research by Gilbert and Mulkay reports considerable variation between scientists on each of these three points (Gieryn 1995, p. 404). Thus essentialist approaches to date are flawed because each is subject to telling criticisms.

Constructivist views of science boundaries

Constructivist approaches to boundary work, on the other hand, seek to articulate explicitly, rather than assume, the question of what is science by describing examples of boundary work in real situations:

The challenge is to explain the cognitive authority of modern science without attributing to it essential qualities found by sociologists to be anything but essential …

Boundary-work occurs as people contend for, legitimate, or challenge the cognitive authority of science - and the credibility, prestige, power, and material resources that attend such a privileged position. Pragmatic demarcations of science from non-science are driven by a social interest in claiming, expanding,
protecting, monopolising, usurping, denying or restricting the cognitive authority of science ... ‘Unique’ features of science, qualities that distinguish it from other knowledge-producing activities, are to be found not in scientific practices and texts but in their representations. (Gieryn 1995, pp. 405-6)

Gieryn describes four types of boundary work, as represented in examples of empirical studies (pp. 424ff).

First is demarcation by monopolisation, where one view dominates and excludes the alternatives. An example is the 1660s debate between Robert Boyle and Thomas Hobbes, which Shapin and Schaffer (1985) characterised as a contest for cultural authority, between Boyle’s experimentation based on the authority of Nature and Hobbes’ rational, deductive philosophy. Boyle’s argument eventually held sway - it monopolised the argument - and the role of experiment was legitimised. As a further point of interest, Shapin and Schaffer argue that this happened less because of any internalist criteria concerning experimentation versus reasoning than with how it was represented and widely accepted as a peaceable and antidogmatic resolution that appealed to diverse interests in Restoration England seeking to construct a peaceable and antidogmatic society.

The second is demarcation by expansion, where insiders seek to push back the boundaries of their field into territory claimed by other fields. An example is D’Alembert’s eighteenth-century mapping of knowledge, which has been characterised as an example of explicit boundary work by outlining three divisions of knowledge, giving great prominence to reason and playing down the scope and authority of memory and imagination (Gieryn 1995, p439).

The third type of boundary demarcation is expulsion, where insiders seek to ‘expel non-real members from their midst’ (Gieryn 1995, p. 432). The example is the posthumous rejection of the work of the eminent British psychologist, Sir Cyril Burt. The anomalies in Burt’s work that progressively came to light were dealt with in ways that demonstrate a concern to identify the field of psychology, but not Burt’s work, as part of science. Thus Burt was first characterised by sloppiness (outside the borders of science because properly done psychology is rigorous like science); second by personal idiosyncrasies and troubles (outside the borders of science); and third by separating Burt’s behaviour and intentions (outside the borders of science) from the content and validity of his claims (inside the borders).

The fourth type of boundary demarcation is protection, meaning the erection of barriers to ‘protect the resources and privileges of those inside’ (Gieryn 1995, p. 434):

Successful boundary-work of this kind is measured by the prevention of the control of science by outside powers - or, put the other way, protection of the autonomous control of science by scientist-insiders. (Gieryn 1995, pp. 434-5)
Examples of boundary-work by protection include dealing with complaints about animal experiments by appealing to the higher values of medical research (inside) compared with cosmetics (outside), and blaming the explosion of the Challenger spacecraft on 'management decisions' or 'manufacturing' (both outside).

The significant boundary is with politics, which is usually kept outside but nearby:

For scientists, the mapping task is to get science close to politics, but not too close. Why? A key to the legitimation of scientists' cultural authority is the perceived pertinence of science for political decision making: As government officials turn to scientists for expert advice before promulgating regulations or statutes, they are simultaneously measuring and reproducing the authority of science over claims about reality (Mukerji 1989). Too great a distance between science and politics threatens a critically important route for scientists' legitimation via their perceived political utility - and in particular their claim on government funding for their research. (Gieryn 1995, pp. 434-5)

The relationship between science and politics is thus symbiotic: this utilitarian role legitimises science, and the appeal to scientific authority legitimises government decisions. Both groups seek to be close but not within the other's boundary: scientists seek to preserve the objectivity and neutrality of their field, and politicians and bureaucrats seek to preserve their discretionary power. This can be achieved in various ways: lobby groups often seek to discredit the science of their opponents; key players in regulation often seek to change the characterisation of an issue from science to politics or vice versa, as it suits their purposes; sometimes the boundary is blurred, as when scientists prepare advice or a position paper; and sometimes the distance between the two is increased, as when scientists working for a government agency (or company) distance themselves from the science of their employer (Gieryn 1995, pp. 435-9). The present thesis argues that in the literature, boundaries between science and non-science are matters of context, argued by combinations of knowledges, activities, purposes, structures and belief systems.
1.3 Context as being ‘internal’ and ‘external’

Much metascientific debate, including debate about the nature of science in the school curriculum, hinges on the distinction between externalism and internalism (henceforth e/i). Internalism and externalism are powerful and recurrent themes in the metascientific literature, whether explicit or implicit, particularly since about the second world war. This distinction is interpreted broadly here, to include ‘the conventional distinction between the content of knowledge and the context of production’ (Callon 1995, p. 51). That is, the distinction is between characterising the intellectual products of scientific cognition as having either cognitive (or internal) sources only or non-cognitive (or external) influences (Shapin 1992, p. 348). The e/i debates excite interest because they underpin many competing characterisations of science within and between scientists, philosophers of science, historians, and sociologists of science.

Debate over contexts of discovery and justification

The e/i debates arose partly in reaction to the positivist RV, which held that the only adequate analysis of a scientific theory is a rational reconstruction of its finished form (Suppe 1979, p. 126). This view distinguished between activities that can be analysed in this way, and others that cannot, which entailed acknowledging the former and rejecting the latter as the proper concern of science. This dichotomy derives from John Herschel’s (1830) distinction between contexts of discovery and verification (Lossee 1980) and Reichenbach’s distinction between contexts of discovery and justification. Herschel (1830) proposed a twofold pathway of reasoning in science: the formation of hypotheses about observations, and then the testing the hypothesis and making predictions from it. He called the process of forming the hypothesis ‘discovery’ (Herschel 1830, p. 199), whether this be careful and cumulative induction as argued by Francis Bacon, or ‘forming at once a bold hypothesis’ (Herschel 1830, p. 198), or a combination of the two; the process of working from the hypothesis he called ‘verification’ (Herschel 1830, p. 208). For Herschel, it does not matter which process generates the hypothesis; the significance lies in whether subsequently the hypothesis is verified or not. This is similar to Reichenbach’s distinction between the contexts of discovery and justification.

The RV, particularly as proposed by Reichenbach’s distinction, dismisses the context of forming hypotheses - discovery - as not subject to rational reconstruction and therefore not a concern of science:

Reichenbach (1938) introduced the phrases context of discovery and context of justification to mark the distinction between the way a scientific or mathematical result is discovered and the way in which it is presented, justified, defended,

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2 As discussed in the companion chapter on activity and in Appendix B.5.
and so on, to the scientific or mathematical community. By this distinction he wishes to mark the difference between, for example, Kepler’s working analogy that the solar system must be analogous to the Holy Trinity and the resulting empirically justified theory which Kepler ultimately presented. According to Reichenbach, problems in the context of discovery properly are the concern of psychology and history, not philosophy; epistemology is occupied only with the context of justification. According to this view, which has been held by almost all adherents to the Received View, a philosophical analysis of theories may ignore factors in the genesis of theories, confining its attention to theories as finished products. Thus rational reconstruction is capable of dealing with problems in the context of justification, hence in epistemology. (Suppe 1979, p. 125)

In this view, reconstructing the logic of the deductive arguments in justification demonstrates the rationality of scientific conclusions.

The alternative position, which is not just the acknowledgment of discovery but of its significant contribution to scientific activity, has become more influential with post-positivist characterisations of science. There are now many metascientific views that address discovery. While both the positivist and post-positivist positions recognise that the notion of discovery entails more than just intellectual or cognitive factors, the former rejects discovery as non-scientific because of this, and the latter views seek to explicate the role of discovery in science for exactly the same reason. The legacy of these e/i debates has been to emphasise the interest in whether science is characterised best by a cognitive context only, or by more than the cognitive, or whether the cognitive depends on other contexts. Thus while a strict internalism is concerned only with the context of justification, the various externalist views acknowledge both the contexts of justification and discovery.

**Classic internalism and externalism**

Internalism and externalism are categories ‘devised by historians for their own purposes and convenience’ and therefore should be understood as tools for understanding science (Morrell 1983b, p. 211)\(^3\). They are of particular interest in the present thesis because in their extreme forms they represent strongly opposing characterisations of science, and the e/i distinction is the subject of considerable, and sometimes intense, metascientific debate. The heat of these debates indicates that e/i arguments are often taken as characterisations, and not merely interpretative concepts; hence Morrell’s caution, above and below.

As interpreted here, the term internalism describes the rejection of psychological, socio-cultural or historical factors and considers only the rational demonstration of cognitive content:

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\(^3\) As are the six categories or dimensions suggested by the present thesis.
Internalist historians focus on the obviously intellectual aspects of setting and solving problems concerned with the understanding and the control of the natural world; they highlight conceptual frameworks, methodological procedures, and theoretical formulations. For these historians, often concerned to defend science as the supremely rational form of thought, changes in past science were exclusively or chiefly occasioned by the solving of inherited and abstract problems within a particular field of inquiry.

The appeals of internalism are real. It avoids the naivety of crude forms of externalism, such as the Hessen thesis. At its best, it reveals science as an awesome intellectual enterprise; and shows the importance in the past of perceptions and attitudes which were often different from those of today. It emphasises the continuity, coherence and progressiveness of science. In its idealist form, it portrays past science as esoteric, imaginative, and creative intellectual work, far removed from routine factual compilation...

Science is a remarkable form of intellectual inquiry. As a non-doctrinaire approach, internalism will therefore remain an essential tradition in history of science, provided it is understood that internalism is nothing more than a category devised by historians for their own purposes and convenience. (Morrell 1983b, p. 211)

(Hessen's thesis characterises Newtonian science by its socio-economic context, an externalist view).

Clearly, the concept of internalism is useful, since it draws attention to a strength of the empiricist tradition, including the RV, as a characterisation of science. That strength, as judged by empiricists, is the attempt in scientific thinking to distinguish the factors that contribute meaningfully to an understanding of Nature from those that do not. The rejection of metaphysical concepts by the logical positivists is an example of this.

In clarifying the characteristics of an internalist view of science, however, Morrell referred to the opposing view, externalism:

[Externalism is] the view that social, political, and economic circumstances affect the pursuit of knowledge of Nature.

Whereas internalism is concerned primarily with science as knowledge, externalism examines science and scientists in the socio-cultural setting. Externalist historians are interested in scientific groups (both institutionalised and informal), the reasons for the development of certain kinds of scientific research, scientific careers and patronage of science. They claim that social and economic circumstances have affected the rate and the direction of some scientific work. Committed externalist historians usually assume that the response to such circumstances has on occasion helped to constitute scientific knowledge itself [as studied in the field of] (sociology of scientific knowledge).

Externalism has its attractions. It sees science as part of culture (in the same way as philosophical ideas and religious beliefs are a part of culture) thereby making history of science a part of general socio-cultural history. It stresses the ways in which political, technical, economic and military interests affect science. Unlike internalism, it asks questions about the location and timing of movements in the science of the past; and it draws attention to the varying receptions of scientific knowledge. Internalism tends to separate knowledge and its uses;

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4 Hessen's thesis is a Marxist characterisation of Newtonian science by socio-economic context, that Newton's scientific work was inextricably tied to emerging manufacturing needs (Shapin 1981b, pp.185-6). The notion of socio-cultural contexts of science derives from externalism, and is addressed later in a dedicated subsection.
while externalism tends to relate them by studying the interests served by the different uses to which knowledge was put...

Externalism is a category devised by historians. For this reason, some see the commitment of Johannes Kepler (1571-1630) to neo-Pythagorean beliefs as external to his work on the laws of planetary motion; others see it as internal. In cases where scientists’ own perceptions give no clues, it is difficult to sustain the distinction between external and internal motives and causes. Because science is a social as well as an intellectual phenomenon, externalism as a non-doctrinaire approach will persist. Generally, however, dogmatic externalism, like its internalist equivalent, is best avoided because it invites distortion and anachronism. (Morrell 1983a, pp. 145-6)

Thus Morrell argues that accepting the insights of these views while avoiding extreme positions is useful. The fact that particular examples can be deemed as internalist in some views and externalist in others supports his cautionary note.

A range of e/i positions

Morrell’s caution against extreme internalist or externalist positions points to a range of other positions that either sit somewhere between the two or else deny the validity of the distinction per se. A number of the summary statements, for example, refer to a ‘standard view’ of science that approximates the RV: they are internalist characterisations of science but do not use the label internalism. This is not surprising: a standard or received view is, by definition, the generally accepted view and does not need to account for its differences from any number of non-accepted views. Its proponents may not even be aware of such alternatives. (This suggestion is itself part of the e/i debate). Beyond the existence or not of such assumptions, however, there is a growing literature that is partly or wholly devoted to developing explicit internalist and externalist conceptions of science, of debating the approaches and questioning the nature and existence of differences between the two. Some examples of these various approaches follow.

a) A strict internalism characterises science as an intellectual or cognitive enterprise and either rejects any influence from external contexts or omits reference to them. The general position of strict internalist characterisations of science is given above in the quote from Suppe concerning the Received View and Reichenbach’s distinction between the contexts of discovery and justification. For Schuster (1990), the ‘canonical’ statement of the internalist position in science history is given in the writings of Alexandre Koyré (1892-1964) which, using the example of the Scientific Revolution, characterise science by the intellectual contents of science, such as concepts, theories and ideas:

Koyré held that the development of modern science depended upon a revolution in ideas, a shift in intellectual perspective, involving the establishment, within or above scientific thought, of a new metaphysics or set of deep conceptual presuppositions, which in turn shaped thinking, experience and action in the emerging fields of modern science, especially classical mechanics and Copernican astronomy. (Schuster 1990, p. 219)
The present thesis interprets this 'intellectual perspective ... or set of deep conceptual presuppositions' as a belief system. A belief system is not necessarily an internalist construct: Borhek and Curtis (1975), for example, have proposed a model of belief systems that comprises a mixture of internalist and externalist notions, that is discussed at length in Appendix B.2. Koyré, however, is clearly concerned with an intellectual, that is internalist, characterisation.

General science texts are usually internalist. They are concerned traditionally with only the cognitive content - the propositions, laws, concepts and so on - and techniques of the particular field of science. Singer has argued that in omitting reference to any context other than cognitive, science texts have perpetuated an internalist characterisation of science, that is, perpetuated a distorted characterisation of science:

In this matter [of confusing or failing to distinguish the three processes of choosing facts, drawing an hypothesis or conclusion, and testing the conclusion] scientific articles, and especially scientific text-books, habitually give a false impression. These scientific works are composed to demonstrate the truth of certain views. In doing so they must needs obscure the process by which the investigator reached those views. That process consists, in effect, of a series of improvised judgements, or 'working hypotheses', interspersed with imperfect and merely provisional demonstrations. Many hypotheses and many demonstrations have had to be discarded when submitted to a further process of testing. Thus a scientific article or book which tells nothing of these side issues, blind alleys, and false starts tends, in some sort, to conceal the tracks of the investigator. For this reason, among others, science can never be learned from books, but only by contact with phenomena. (Singer 1959, pp. 256-6)

Externalist writers, mostly writing later than Singer, add a range of other factors whose omission also distorts an accurate characterisation of science, but would certainly agree on the central point of the distorted view. Of course, traditional characterisations of science as knowledge or a conceptual framework are internalist characterisations. This thesis specifically addresses scientific knowledge, including its common internalist characterisation, in the companion chapter on knowledge and Appendix B.6.

b) A less strict internalism is the view that, ideally, science has an intellectual context only, but that in practice some external factors impinge on the proper (internal) working of science. Other (external) factors include the personalities involved (psychological context), strategic and tactical considerations (political contexts), and the availability of the state-of-the-art facilities (organisational and physical contexts). Many general historical accounts, including some that are not so recent, either represent or include (mostly) internalist histories because they focus on the development of logically justified concepts and not their discovery or invention, but mention other factors (see Singer 1959, 1960; Mason 1962; ed. Williams 1969; Losee 1980; eds Bynum, Browne & Porter 1983; and Oldroyd 1989). Mason and Oldroyd include a wider range of contextual factors, but nonetheless the emphasis in each is on the intellectual context. As

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5 See chapter 7.
part of their dictionary format, Bynum, Browne and Porter do address externalist factors specifically (as in Morrell’s entries, above) but in general the entries are not from an externalist perspective.

c) In the middle of this notional continuum, the relative standing of e/i positions is less clear: views may characterise external factors as constituting internal science, or internal factors as constituting external science. The former includes the view that science is an intellectual enterprise characterised by external factors: that the essential or defining concerns of science are indeed intellectual, as the internalists argue, but that these cannot be properly understood without considering the range of external factors that contribute to and shape them. The latter is similar, but arises from a different set of analytical interests. In this approach, science is best understood as a social enterprise centred in a particular group of subcultures, which are characterised particularly by intellectual factors. For example, in discussing the diversity of views among sociologists of science, Shapin (1992) observes that many are sceptical of e/i factors and do not feel the need to invoke external factors to explain science as an essentially social enterprise:

While arguing for the irreducibly social character of scientific activity, it was never any of these sociologists’ (of scientific knowledge) case that considerations pertaining to the wider society (what are conventionally called ‘external factors’) must be part of any particular sociological account. Whether or not an externalist account was indicated was regarded as a wholly contingent matter. Indeed, sociologists noted, it is entirely plausible that the professionalised and insulated status of much modern science means that considerations relating to individuals’ party-political affiliations, class background, religion, and the like are rarely relevant to explanations of theory-choice or fact-judgement. (Shapin 1992, p. 352)

Bhaskar’s scientific realism can also be interpreted as a middle ground position. It posits an independent reality that determines the cognitive possibilities for us, while requiring analysis of the social production of this knowledge (Bhaskar 1983k, p. 363).

d) A strict externalism characterises science as a social enterprise of no special status: that science is an activity within society and is best understood by being interpreted in the way that all other subcultural groups are interpreted, and not according to the constructs used within the group itself. Thus Bunge (1991, p. 538) distinguishes ‘moderate or weak externalism’ from ‘radical or strong externalism’:

*Moderate or weak externalism: Knowledge is socially conditioned.*

- M1 (Local). The scientific community influences the work of its members.
- M2 (Global). Society at large influences the work of individual scientists.

*Radical or strong externalism: Knowledge is social.*

- R1 (Local). The scientific community emanates or constructs scientific ideas, all of which have ultimately a social content.
- R2 (Global). Society at large emanates or constructs scientific ideas - hence there are no inside-outside, micro-macro, content-context, and discourse-praxis distinctions. (Bunge 1991, p. 538)

Note that Bunge identifies a strong externalism with a rejection of e/i boundaries; he cites Latour’s (1987) characterisation as an example of a radical externalism. By way of
comparison, Latour is for Shapin an example of how a rejection of e/i distinctions dissolves the conventional differences between science and society and gives fresh insights into science:

Latour rightly points out that what counts as 'science' and what counts as 'society' are the results of trials of strength. Thus, to speak of 'social influences on science' is, in the current sociological commonplace, to use as a resource what ought to be a topic of inquiry ... He argues that we do not encounter modern social action without encountering also the technical and scientific, and symmetrically, that we never confront science without confronting social action and politics. The objects which students of science seek to analyse are never 'pure science' and 'pure society': they are 'actor-networks' in which the humans are connected to other humans, things to other things, and things to humans. Where is the external social which is said to influence science? And what is the internal domain which is said to develop according to its immanent logic? The traditional e/i debate is said to be vacuous because it manipulated the wrong ontology.

As a metaphysics for science studies, Latour's actor-network theory ... rightly dissolves any discourse which depends upon 'society' and 'science' having distinct real essences. Yet it remains unclear what historians and sociologists are supposed to be able to do with the new ontology ...

According to Latour, historians and sociologists should no longer talk of 'science' and 'society' but only 'stronger and weaker associations' of heterogeneous elements. We must, he says, abandon e/i discourse because crucial terms in that discourse are analytically invalid: 'science' and 'society' do not exist as pure forms, and certainly not within their common-sensical boundaries ... So far as the historicist practitioner is concerned, Latour's metaphysics appears as a useful way, along with others, to clear the mind of some current prejudices before setting out to study science. (Shapin 1992, pp. 355-7)

Unsurprisingly, Latour's characterisation has provoked some reaction. From an internalist perspective, 'trials of strength' are acknowledged only to the extent they are trials of evidence, and other shows of 'strength' such as political or rhetorical are dismissed as non-science. From some externalist perspectives, trials of any kind of strength may have affected the scientific outcome but are not identified unless we look for them and their effects. For Shapin, above, and others, Latour offers a framework into which can be placed e/i issues of context. For others, such as Bunge (1992, pp. 51ff), removing the distinction between work inside the laboratory and other work removes the opportunity to analyse critical characteristics of science especially mental processes, or internal factors. Bunge identified in what he calls the NSS (new sociology of science, particularly Latour & Woolgar, Knorr-Cetina, and Latour) a critical lack of attention to fundamental internal characteristics, combined with attention to largely misleading external factors:

The advocates of the NSS ... [assert] that there is nothing special about science, 'nothing of any cognitive quality.' Thus to quote Latour (1983): 'Scientific fact is the product of average, ordinary people and settings, linked to one another by no special vices' (p. 162). Never mind what the inscriptions mean and how their content is checked for consistency and truth: Only the 'technology of inscribing (writing, schooling, printing, recording devices)' matters ...
The constructivist/relativist view of scientific research is a sociologised version of Bacon's, according to which the scientists are only busy with collecting (or rather constructing) data, making inscriptions ... Somehow the spotting of problems, the conception of hypotheses, the design of experiments, and the checks for truth do not occur in the 'Wittgensteinian/phenomenological/Kuhnian model of scientific activity,' as Collins (1983) calls it.

Thus Latour and Woolgar (1983) and Knorr-Cetina (1981) believe that the essence of laboratory work is the manipulation of artefacts ... (Bunge 1992, p. 57)

For Bunge, these characterisations are merely operationalist and confuse the means (the artefacts and observable activities) with the ends (the construction and testing of theories, essentially internalist activities). The reply to Bunge's critique is that the rationalisation of science from within the culture of science proves nothing to those seeking to characterise it objectively from without. Hence the appeal of Shapin's position, in part (e) below, that there remains much to do in resolving e/i issues about context in science. Nevertheless, externalist characterisations such as Latour's are useful resources in understanding science, and are employed, in turn, in the other characterisations.

e) Other positions are more reflexive in terms of the e/i debates, arguing that the e/i debates are unclear and need clarification, or that the arguments arising from an e/i distinction are not meaningful, and that alternative conceptions are more useful. Thus, Shapin (1992) has argued that, while e/i debates were prominent in the academic history and sociology of science from about the beginning of the Second World War, they are no longer perceived as useful or even meaningful ways to characterise science:

If in the 1960s the central problematic of the academic discipline known as the history of science was pointed to by reference to the 'internal' and the 'external', by the late 1980s such usages increasingly betrayed the amateur, the neophyte, the outsider, or the out of touch. Within a generation the discourse of 'internalism' and 'externalism' seems to have passed from the commonplace to the gauche. (Shapin 1992, p. 333)

As an example, Fuller (1991, p. 232) judges STS as the 'successor' to HPS, largely because HPS became 'embroiled' in e/i debates, while STS, claiming contributions from historians, philosophers and social scientists, addressed instead more productive images of science. He broadly aligns HPS and STS with internalist and externalist positions, respectively. Bunge (1991) takes a contrary position to Fuller, and identifies externalism as a characteristic of both the SS and the NSS. He judges the SS, given in Bernal (1939), Price (1964) and Merton (1938; 1973), as useful in distinguishing 'the conceptual content of science from its social context and [holding] that the latter influences the former without, however, fully determining it' (Bunge 1991, p. 534). However, he judges the NSS, given in Knorr-Cetina and Mulkay (1983), Barnes (1977), Bloor (1976) and Latour and Woolgar (1979), as a 'regression' because its stronger case for external factors fails to make the same distinction (p. 525). Similarly, Slezak (1994a; 1994b) has criticised developments in SSK because of a perceived strong externalism. These positions contrast with that of the influential report, *Science for All Americans* (AAAS

An alternative meta-analysis of these debates sees them as unresolved and needing further consideration. This view is more likely to accept some tension between multiple viewpoints, and in this sense acknowledges a post-modern eclecticism: e/i distinctions of some sort remain useful constructs for characterising science. In discussing the judgement that e/i distinctions are no longer current, Shapin (1992) pleads for a more critical appraisal of e/i issues before laying the debate to rest. For the purposes of the present thesis, the very existence of e/i debates demonstrates vigorous characterisations of science that foreground context.

Shapin’s critique of the e/i discourse

Shapin (1992) provides a useful critique of the e/i field. He argues for maintaining an interest in e/i issues, albeit a more pragmatic and sceptical interest, including a more systematic consideration of e/i issues that remain unresolved to his satisfaction. His discussion of shortcomings in the several decades of e/i debate comprises a basis for a map of the field, indicating areas both having received attention and needing attention. First, e/i theories were never clear about e/i characteristics, and were typically characterised by opponents to make them extreme or ‘indefensible’.

Secondly, there has been confusion between e/i as referring to a theory of change - ‘scientific change proceeds (wholly/mainly/partly) in response to intrinsic/extrinsic factors’ - and as referring to a focus or approach to research:

Thus, externalism and internalism have been widely treated as those styles of research which happen to attend (wholly/mainly) to factors attracting the labels ‘external’ or ‘internal’. Yet a practitioner who attends (generally or in a particular instance) to external factors may hold (in general or in that instance) an internalist theory of scientific change. And vice versa. ... A style of research does not amount to a theory about scientific change. (Shapin 1992, p. 346)

Thirdly, eclectic mixtures of external and internal factors relied on seeming generally sensible and failed to explain how such mixes actually resulted in scientific change. Fourthly, there is an asymmetry between e/i accounts: it is possible to suggest a completely internalist account of science history, but not an externalist one.

Fifthly, there is wide variation, overlap and ambiguity between what different accounts consider to be external and internal:

Thus in one form of accounting, external explanation is established by showing the influence of non-scientific forms of culture upon science, while in another the entire domain of the cultural (or cognitive) is taken as intrinsic and only the non-cultural as extrinsic. Externalist accounting has, in various manifestations, identified its explanans as non-scientific culture (erroneous, irrational, metaphysical, aesthetic); scientific culture other than the variety allegedly influenced; yesterday’s science (traditions or authority structures); social structures and processes within science (such as interested attachments to methods, schools and knowledge-claims); social and economic structures
outside of science (considered as non-cognitive, and actively conceived as interests or passively as reflections of extrinsic realities). Similarly, externalist explananda have been characterised as encompassing scientific culture as a whole, including its methodological and metaphysical elements, its dynamics or foci of interest. Debates have been so poorly focused that the general form of 'key' achievements in externalism have been taken as identifying the 'key' tenets of internalism. (Shapin 1992, p. 348)

Shapin interprets this variation as the imprecision of the field. This is significant in the present thesis, but perhaps more significant here is that this variation constitutes a useful 'map' of the 'territory', that is, the various ways in which science is characterised by context. Shapin presses the point by invoking 'arrangements of present-day science' as examples of externalist influences on different research areas of ‘internal’ science:

... However vigorously modern scientists may strive to blend politically endorsed directives to their own ends, it is unlikely that anything like a Human Genome Initiative would have autonomously emerged from an internal agenda of molecular biology. The identification of ‘disinterested curiosity’ as an individual motive is not incompatible with the claim that curiosity tends to flow towards the heaviest concentrations of cash. ‘Actor-oriented’ analysis is laudable but it is also insufficient, since other actors may affect the behaviour of those in whom we happen to be interested. (Shapin 1992, p.348)

Sixthly, there is no adequate explanation of causation: the externalists (with the Cartesians) have not explained how the non-cognitive shapes the cognitive, and the internalists (with the idealists) have not explained how ideas cause ideas, since it implies agency or action to products of human agency. The related concept, of an e/i division into science as cognitive and society as non-cognitive, has not been ‘systematically defended’ either (Shapin 1992, p. 349).

Seventhly, the point of action of e/i theories is unclear: the notion of individual motivation common in externalist accounts is often unclear, and the notion of ideas causing other ideas in internalist accounts has not addressed questions of psychological and sociological influences.

Eighthly, the commonly made equation between ‘external’ and ‘social’ is unjustified, and ignores sociological factors within science. Although there has been much work in STS from the 1970s identifying ‘social influences’ in scientific claims, the equation between the external and the social remains influential. This influence reflects a long-standing tradition in western European cultures that assumes that rational thought is the activity of an individual:

It is a pervasive way we have in our culture of stipulating the posture and circumstances in which valuable culture ought to be made. Many features of the history of these debates, including explicit statements by participants, lend support to the notion that e/i was deeply shaped by concerns to say ‘good’ or ‘bad’ about science. In important respects, this evaluative-descriptive discourse traces back to the Greek preference for contemplation (theoria) over praxis, and it surfaced in just that form in the 1930s and 1940s debates over whether modern science emerged in the isolated scholar’s study or the craftsman’s collective workshop. Both the secular-philosophical religious sensibilities
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stipulate solitude as the proper site for the appearance of truth. And empiricist-inductivist models of scientific discovery are powerfully supported by individualistic conceptions of social order. In the 1980s, philosophers’ role in the e/i debates predominantly took the form of a defence of reason against ‘the social’, and, even though important philosophical resources were available for understanding scientific activity as a collective phenomenon, some of the most polemic interventions by philosophers of science simply assumed the validity of contrasting ‘the rational’ and ‘the social’. (Shapin 1992, pp. 350-1)

Finally is the tendency to interpret historical examples using present-day interpretations of science e/i boundaries. Given the different interpretations of what the e/i field is, this clouds historical analysis.

Shapin’s argument for further attention to e/i debates, and rejection of absolutist characterisations, suits the purpose of the present thesis in its attempt to describe and ‘map’ the variations in characterisations. Further, the present thesis interprets the difficulties Shapin described as arising from inadequate characterisations of science.

Schuster’s critique of the e/i discourse

Schuster is more strident in his criticism of e/i debates (and of the continuity/revolution debates, discussed below). He has argued that they are ‘self-defeating’, ‘dominated by the clash of simplistic interpretations’, and lingering ‘for the lack of anything better’ (Schuster 1990, p. 222). He puts this down to the internalists concentrating exclusively on cognitive issues and the externalists on social issues:

Internalists were inclined to believe that scientific ideas have a special and autonomous cognitive status, and hence the history of science unfolds through the internal logic and dynamics of ideas alone. They failed to grasp that scientific sub-cultures are relatively autonomous just because they have well-developed social and political micro-structures through which knowledge is produced, and that the micro-structures are variously exposed to, and depend upon, the larger factors studied by the externalists. A similar point was missed by the externalists from the other direction. Concentrating on large-scale social and economic factors, they were loathe to grant autonomy, and an inner dynamic, to intellectual traditions and subcultures. Therefore they, like the internalists, failed to appreciate that intellectual sub-cultures are not merely systems of ideas, but also have ‘internal’ social structures, and political dynamics, partially buffered from the direct impact of larger factors, through which knowledge is manufactured. (Schuster 1990, pp. 222-3)

Schuster’s argument is that both the e/i debates and continuity/revolution debates arise from a universal but false assumption that there is a simple defining feature or characteristic of modern science, whose cause will explain, for example, the Scientific Revolution. Hence the debates: different views entail different defining dimensions, which are then turned into historical categories and become bases for historiographical analysis. Schuster’s solution is to recognise this flaw, and instead construct an alternative characterisation of the sciences as ‘sub-cultures’ and ‘social and cognitive enterprises’ (Schuster 1990, p. 223).
The general utility of an e/i distinction

The e/i distinction and the accompanying debates are useful in clarifying characterisations of science. For the purpose of the present thesis, it is clear that (a) e/i distinctions represent a considerable literature that clearly characterises science by context, and (b) concepts based on e/i distinctions remain useful in informing us of the ways in which science has been and can be characterised. Granted, the e/i debates to date are flawed, and even 'analytically flawed' (Shapin 1992, p. 334). However, the debates have touched on significant issues in developing our understanding of science and should not be dismissed without assessment. Besides the direct characterisations they provide, they have other implications in discussing characterisations of science.

First, e/i debates arose, and continue to arise, quite legitimately as exercises in establishing the boundaries between what is agreed as a field (in this case science) and what is not. Boundary concerns are foci for discussion not only by metascientists, but also in wider society, as discussed in section 1.2 above.

Secondly, whilst accepting all the cautions about embracing extreme e/i positions, an e/i framework can still usefully inform the rise of more eclectic interpretations of science. Extreme externalism, such as in Zilsel6 and especially in the early 1950s, was relatively short lived and replaced by a more eclectic approach that advocated a judicious mix of e/i factors and avoiding extremes. This is Morrell's approach, above. The sensitivity to nuances in eclectic approaches suits the wider 'jumble of post-modernist sensibilities' (Shapin 1992, p. 345).

Thirdly, the insights from e/i debates can inform further metascientific analyses. For example, Shapin suggests two possible methodologies. One, following Barnes (1974), is historicism, in which: (a) historical events be interpreted in their own terms, (b) a 'naturalistic actor-oriented inquiry into scientific boundaries' be used (Shapin 1992, p. 352) and (c) caution be used where describing actors' positions will exclude other actors. The other is Latour's (1987) abandonment of distinctions between science and society.

Finally, e/i distinctions provide grounds for caution about interpreting metascientific analyses and characterisations simplistically. Note that the collections of viewpoints identified in Table B.1.1 not only differ, but that an e/i distinction does not correspond to a distinction between HPS and STS approaches (however each of these terms is interpreted). Few current positions in HPS are strictly internalist and few in STS are strictly externalist. Constructivist approaches such as Kuhn (1959), Toulmin (1961, 1972, in Suppe 1979) or Hanson (1958), and scientific realism such as Bhaskar (1975) or Chalmers (1976), incorporate similar insights to those from constructivist STS

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6 Zilsel's thesis 'related the emergence of modern science to social change in early modern Europe' (Shapin 1981b). It is discussed in section 2.6(a), below.
approaches. Likewise, many positions within STS do not deny internalist characteristics but seek to provide a more accurate account by addressing a more comprehensive set of factors.

Most importantly, taking a position on what is allowed as a statement of legitimate context is fundamental to many characterisations of science, both in scientific and wider forums. It is therefore grist to the mill for the present thesis.

Other analyses of context can be made besides those based on e/i questions, of course. Given that some commentators now see the e/i debate as no longer useful, the very use of the term context could be seen to reinforce the e/i dichotomy, and so mire the present thesis in old debate. However, context remains a useful label for a category of characterisation, and although e/i issues are passé for some metascientists, they remain contested by others. This is especially so for curriculum stakeholders, who cannot be expected to be up to date with every position within such broad fields as science and metascience. The following sections will illustrate this by sketching analyses focussing on historical, intellectual, socio-cultural, human, organisational and physical contexts.
1.4 Historical contexts of science

There is a general sense of an historical context of science, in which we understand present day science to have antecedents. An historical context is useful both in its own right, as any history is of interest, and more importantly here because understanding the antecedents affords us a better understanding of how contemporary science came to be as it is. There is also a more restricted sense of historical context, in that at least descriptive histories of science provide much the same account, which is generally identified as the western (European) scientific tradition.

Restriction to a western European scientific tradition

The present thesis is concerned mainly with the western European scientific tradition. This is the notion of Aristotle, Ptolemy, Copernicus, Galileo, Newton, Einstein and others as constituting a tradition of science, a well-known characterisation of science history. The notions both of a generally undifferentiated, single ‘western’ culture, and of a similarly undifferentiated, single tradition of science, are both problematic. That this tradition of science emerged largely in western Europe must be reconciled with its practise now in diverse cultures around the world, but the label reflects its history. In this and in some other respects the notion of what constitutes a ‘western’ culture, or for that matter a ‘European’ culture can be contested, but this level of cultural analysis is beyond the scope of this thesis.

The reader is reminded that the present thesis specifically addresses the western European tradition of science because it is that tradition that comprises, largely or wholly, the content and justification of science in the school curricula that concern this thesis. This is so even where some curricula have begun to include examples of ‘science’ from other, non-Western cultures. The present thesis claims to apply to those curricula, but it seeks firstly to inform the characterisation of western European science, since that is the science of primary (and sometimes the sole) interest to the curriculum stakeholders. However, even the very term science should be used cautiously in cross-cultural contexts, because Anglo-European meanings associated with its use may not apply in the same way in other cultural contexts. This is discussed more fully in section 1.6, below.

The notion of a scientific tradition

The case for an historical context for science is easily made: under the title of history of science there is a substantial literature, courses of study and departments in universities. The notion of a western European scientific tradition is well known, particularly as given in a large number of texts with both general and particular themes. (See, for example, the bibliography in the present thesis, and the entries and bibliographies in Bynum, Browne and Porter (eds) (1983), and in Olby, Cantor, Christie...
and Hodge (eds) (1990)). Depending on the detail of the particular history, a fairly common sequence of names is given in demonstrating this tradition: typically from the Ionians, Plato and Aristotle and others in ancient Greece, through Arabic science and the Middle Ages to the Scientific Revolution with the likes of Copernicus, Galileo and Newton, down to Kelvin, Rutherford, Bohr, Einstein and others in the twentieth century. For example, Thorndike (1923-58), although interpretatively dated, provides extensive historical detail of investigative activity. This list is characterised commonly as a tradition, and hence a context, because ideas and arguments are identified as sequences in which individuals refer to antecedent ideas and arguments in making their own positions. Thus Aristotle referred to the Ionians and Plato, Francis Bacon referred to Aristotle, and so forth. There is no point in recounting these histories here; rather, the assumption will be made here that the reader has at least passing familiarity with this history of science and certainly has access to such general accounts. The present thesis is more concerned to show how it is this tradition that forms part of the arguments that (1) the history of Western European culture is partly characterised by its science, and that (2) Western European scientific tradition is unique. Certainly the notion of this historical tradition - as the context within which science has operated - is a widely known concept by which science is characterised.

The tradition referred to above is known commonly as the western scientific tradition, or some variant of it, as in this example:

Modern science owes most of its success to the use of these inductive and deductive procedures, constituting what is often called ‘the experimental method.’ The thesis of this book is that the modern, systematic understanding of at least the qualitative aspects of this method was created by the philosophers of the West in the thirteenth century. It was they who transformed the Greek geometrical method into the experimental science of the modern world.

The outstanding scientific event of the twelfth and early thirteenth centuries was the confrontation of the empiricism long present in the West in the practical arts, with the conception of rational explanation contained in scientific texts recently translated from Greek and Arabic. (Crombie 1953, p. 1)

This tradition is characterised commonly as an almost linear development of ideas, with little indication of context. Intellectual context is restricted typically to the explicitly antecedent ideas, with little mention made of the many concurrent debates between competing ideas, except for a small number of examples like the phlogiston theory. Less attention still is given to the influence of factors external to the actual ideas themselves and the very assumptions that there is such a tradition. Singer (1959) notes that this portrayal has had the effect of distorting the representation, or what in this thesis is called the characterisation, of science.

The notion itself of an historical tradition dates from the middle of the eighteenth century in Europe, and has influenced the characterisation of science:
We can date the emergence of this specifically historical concern with the global and epochal significance of science to the middle decades of the eighteenth century. It is associated with the intellectual movement which dominated that time, known to historians as the Enlightenment. (Christie 1990, p.7)

In standard histories of Western European science, the scientific tradition is considered to have arisen just once, with the Ionians in ancient Greece, while the direct antecedents to modern science are more commonly regarded as dating from the period of the Scientific Revolution. For example, Singer (1959, pp. 3-5) has observed that while elements of what is known now as science can be discerned in even the most ancient civilisations, the Greeks were the first to theorise about how scientific ideas developed and how these ideas influenced beliefs in the general culture. (The significance of these beliefs is addressed in the companion chapter on belief system and their distinctiveness can be gauged by comparison with other cultures there and later in this chapter.)

From these early times developed beliefs, concepts and techniques, some of which proved to be antecedents for subsequent science. The following arbitrary examples include some well known themes and names, drawn from entries in Macmillan Dictionary of the History of Science (eds Bynum, Browne & Porter 1983). There is an example for each of belief system, activity, purpose, knowledge, structure and context, to show that any dimension of science can be considered in its historical context:

a) The belief that the cosmos is subject to arithmetic analysis can be traced through:
   • the numerical analysis of vibrating strings and ascription of occult meanings to natural numbers, by Pythagorus (c560 - c480 BC);
   • the development and application of mathematics by Plato (427-347 BC), Brahe (1546-1601), Descartes (1596-1650), Newton (1642-1727), Einstein (1879-1955) and Hawking.

b) The techniques of dissection, as used to understand and manipulate the structure and function of living things, can be traced through the dissection work of Alcmaeon of Crotona (fl c500 BC), da Vinci (1452-1519), Vesalius (1514-1564), Harvey (1578-1657), and Grainger (1801-1865).

c) The aim of developing an understanding of the cosmos based on natural, rather than supernatural, causes can be traced through:
   • the first recorded naturalistic explanation (Thales of Miletus c624-546 BC);
   • the classification of matter into the four elements, air, earth, fire and water, which tend to their natural places (Empedocles c492-432 BC);
   • the explanation of substances as discrete, not continuous, and comprising unchanging particles called atoms (Democritus c460-371 BC);
   • the appeal to observation (Aristotle 384-322 BC),
   • the appeal to inductive reasoning based on as broad a base of observations as possible (Francis Bacon 1561-1626),
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- the notion of facts as stable clusters of sensations (Ernst Mach 1836-1916);
- the explanation of the radiation field of a charged particle as action-at-a-distance, according to a relativistic interpretation of Dirac’s quantum electrodynamics, and using experimentally-determined values (Richard Feynman 1918-s1988).

d) Our (chemical) knowledge of the properties and relations of matter can be traced through:
- the opposing beliefs that the cosmos in constant change (Heraclitus 540-475 BC) or essentially unchanging, from Parmenides (c515-c450 BC);
- the body of alchemic understandings of the elements (Paracelsus 1493-1541);
- the corpuscular theory of matter based on experimental experience (Robert Boyle 1627-1691);
- the identification of solubility and temperature as factors by which chemical reactions can be reversed (Berthollet 1748-1822); and
- the classification of chemical reagents on the basis of whether electrons are transferred or shared in reactions (Ingold 1893-1970).

e) The relations between the sciences have been structured and restructured numerous times throughout the history of science (Porter 1983b), for example as:
- the three fundamental types of knowledge, geometry, arithmetic and music (acoustics), by Pythagoras (c560-c480 BC);
- the three purposes or end-uses of knowledge, being the theoretical sciences (physics and philosophy), the practical sciences (ethics and politics) and the poetic sciences (aesthetics), by Aristotle (384-322 BC);
- the three classes of certainty of knowledge, being philosophy (knowledge of things by causes), history (knowledge of things as facts), and poetry (feigned knowledge), by Francis Bacon (1561-1626);
- the ranking of knowledge from the abstract to the complex, being mathematics, astronomy, physics, chemistry, biology and sociology, following August Comte (1798-1857);
- the historical division into those dating from antiquity which are relatively abstract and deductive (such as arithmetic and geometry), those dating from only the last couple of hundred years which have an experimental basis (such as biology, geology and the expanding number of hybrid fields emerging in the twentieth century), and chemistry, which straddles the two.
f) The notion of an historical tradition of western European science is supported by the statements (a) to (e) immediately above, but is more strongly made by pointing out that the people in such lists typically acknowledge the earlier contributions of others, as we have seen.

Some accounts of a scientific tradition are more interpretive and seek to explain the nature of changes. That is, they seek to explain how and why changes came about, and not just give the changes. For example, rather than describe the changes in accepted science knowledge, Oldroyd (1989) has traced the development of hypothetico-deductive reasoning, and its impact on knowledge and beliefs about knowledge. Also, Redner (1987) has argued that there have been three epochs of science history that are characterised not just by differences in knowledge content, but also by different criteria of what constitutes knowledge and what the knowledge means. Oldroyd’s account is discussed in Appendix B.5; Redner’s is discussed in section 3 of Chapter 6. Accounts such as these are significant in the present thesis because they show clearly how deeper analysis and understanding is helped by accounting for the multidimensional character of science.

Whig histories and other approaches

Historical analyses, particularly from the second half of the twentieth century, have tended to become more critical of older science histories for being partisan or Whig histories. In a general sense, Whig or liberal histories have tended to ‘favour progressive movements in history’, identify contemporary beliefs and practices as the goals for previous beliefs and practices, and reconstruct ‘the progressive march of history focussing on those past developments which anticipated the present’ (Wilde 1983, p. 445). Such accounts therefore tend to ratify, if not glorify, the successful revolutions and individuals, and judge past events and controversies in terms of the present. Many of the earlier histories of science have this approach to characterisation, and its effect remains in, for example, the overwhelming preponderance of material on the successes Newton and Darwin, compared to their failures and those of their contemporaries. The belief that the positivist knowledge of the Received View was superior to earlier knowledge is another example. Current characterisations emphasise the value in interpreting historical events in their own terms:

[H]istorians have demonstrated the superiority of an approach which attempts to reconstruct, in all their aspects, the problems faced by earlier thinkers rather than judging the past with the benefit of hindsight ... [They have also] shown that many ideas which have been superseded and may even appear ridiculous to the modern scientist, played an important role in the early development of the sciences by focussing attention on problems and organising the investigation of them. Aristotelian physics, phlogiston theory and Mosaic geology are three examples of such ideas. (Wilde 1983, pp. 445-6)
Thus the Whig histories, mostly older accounts but also some recent popular ones, tend to ignore or devalue those who opposed or confounded progress to where we are now, and instead trace the successful precursors to contemporary science in terms of contemporary science. More recent scholarly histories present mostly different characterisations, attempting to interpret events more in their own terms.

Science history as continuous or discontinuous

While e/i debates have been the subject of considerable historiographical and metascientific interest, as discussed above, another contested point has been the characterisation of scientific development as essentially continuous or discontinuous; that is, whether science history is characterised essentially by revolution or continuity (Schuster 1990, pp. 217ff). As with the differences between e/i positions, or between Whig and other histories, the revolution/continuity dichotomy is another difference between historical characterisations of science:

Some historians of science, such as Butterfield, Kuhn and many others, have seen the science of the seventeenth century as marking a radical departure from the science of all previous periods; and they speak confidently of 'The Scientific Revolution'. Others such as Duhem and Crombie, however, have been inclined to trace science back from the seventeenth-century science movement, emphasising rather the continuities with earlier theories and practices, though not thereby underestimating the seventeenth-century achievement.

It would also be possible to emphasise historical continuity or discontinuity at the metascientific level as well as at the level of science itself. Undoubtedly, some seventeenth-century writers on metascience, notably Bacon and Descartes, emphasised the novelty of their methodological pronouncements. But ... it is not difficult to observe the ways in which certain aspects of their thought clearly betrayed their intellectual ancestries. And the same may be said of Galileo's metascientific remarks, even though his own scientific work was so very distinctive, involving specifically a mathematisation of physics, with the selection and isolation of particular features of the observed phenomena for experimental examination and mathematical description. (Oldroyd 1989, p. 48)

For example, Bronowski (1978) sees the scientific Revolution as a hugely significant event in human history, marking a fundamental departure from ancient mythology, and 'an irreversible step in the cultural evolution of [humanity]' (p. 2). He chides C. P. Snow and others for emphasising the undoubted continuity from 'before the Middle Ages into modern science ... [B]ut it is my view that those continuities give a false perspective of the great threshold from which the burst of modern science comes' (Bronowski 1978, p. 23).

As with e/i debates, a case can be made that revolution/continuity arguments are deployed by involved parties as a means of explaining revisions and reinterpretations in science:

... In other words, no revisions are inherently and essentially revolutionary or continuous in nature; rather these terms are deployed by interested parties ... seeking to explain the process. On the one hand, historians who advocate continuity are simply over-stressing the existence of conceptual borrowing and
reinterpretation. They therefore tend to hypostatise a history of ideas and their inner, gradually unfolding logic of development. On the other hand, historians who advocate revolutionary displacement of conceptual fabrics are simply overplaying the fact that no revised conceptual framework is exactly like any previous one. A case for ‘revolution’ can almost always be made out by selectively stressing certain aspects of change at the expense of others. (Schuster 1990, p. 223)

This does not deny the revolutionary characteristics of many scientific changes such as evolutionary and relativity theories. However, it does remind us of elements of continuity and development and, importantly in the present thesis, highlights the differences between views as significant indicators of characterisation. Most significantly for the present thesis, ongoing debates about historical interpretation argue that there is no ‘fixed’ history of science, and that revisions in historiography show continuing interest in characterising science by its histories.
1.5 Intellectual contexts of science

Simply interpreted, the intellectual context of science is the set of cognitive resources, including ideas, the accepted science knowledge and the intellectual climate, available to scientists which they use to describe and explain Nature. As the intellectual context that surrounds and shapes scientific thinking, it can be considered both as the internalist notion of the conceptual framework and as the externalist notion of other non-scientific conceptual resources - ideas, concepts, beliefs - that influence scientific thinking. Standard internalist histories of science are replete with ideas that have been progressively developed in science, and so represent the development of an intellectual context. For example, Ronan (1982) credits Heraclitus with establishing a view, taken up by others later in history, that the cosmos is essentially changing, rather than essentially constant:

... in an unstable state of flux, so that what we perceive with the senses is somehow transitory, not true knowledge - a view which was later to receive wide currency and militate against setting too much store by practical observation. (Ronan 1982, p. 71)

This view is part of the intellectual context of the rationalist approach, what Kuhn would later call the paradigm, associated with Plato and his followers. There are similar conceptual antecedents for Aristotle, for example. In describing the physical world, Aristotle drew on concepts handed down from earlier thinkers, such as the geometry of Pythagoras (Singer 1959, pp. 52-56). The influences of existing beliefs within his society were thus his intellectual context: the belief in the perfection of the circle, for example, underpinned his proposal that the sublunar and celestial regions above were spheres. Circularity as the basis for cosmological structure also dates from Pythagoras. Likewise the schema of the four elements, which he increased to five, dates at least back to Empedocles and Aristotle’s version again shows influences from Pythagoras. The difference between celestial and terrestrial physics was also part of the intellectual context in which Aristotle worked: that two different physical systems operated was accepted at least as far back as the Pythagoreans. In turn, historians trace the continued use of Aristotle’s natural philosophy in Arabic countries and in mediaeval Europe, its eventual critique and replacement in the sixteenth and seventeenth centuries by other concepts, and the subsequent development and critiques of the newer ideas. Thus within science there is often the sense of a shared historical-intellectual tradition or context:

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7 These and other dimensions are addressed in the companion chapters on knowledge and belief system, and at greater length in Appendices B.2 and B.6.
8 Kuhn’s now-widely used concept of paradigm is more than just the intellectual context, although the intellectual context would be taken by most to be part of a paradigm. Paradigm is a complex concept, partly because it was imprecisely defined in the first place and partly because it was later widely interpreted. This is discussed below in section 2.6.
The communal character of science is further reflected in the recognition by scientists of their dependence upon a cultural heritage to which they lay no differential claims. Newton’s remark - ‘If I have seen farther it is by standing on the shoulders of giants’ - expresses at once a sense of indebtedness to the common heritage and a recognition of the essentially cooperative and cumulative quality of scientific achievement. (Merton 1942, in Barnes (ed.) 1972, p. 74)

It is this intellectual context that includes the body of knowledge by which science is so commonly characterised: that Newton used concepts and beliefs that were available to him and enjoyed some acceptance.

The two cultures debate

A widely known and enduring theme in academic circles is to oppose the intellectual context of science against that of literature and/or religion (Seymour-Smith 1988). It is probably best-known as the ‘two cultures’ debate, after the Rede Lecture at Cambridge by C. P. Snow (1959), *The Two Cultures and the Scientific Revolution* and the reply by F. R. Leavis (1962) in the Richmond Lecture at Cambridge:

Snow diagnosed society’s intellectuals as divided, unable to speak to each other, having no common language. Each group he called a ‘culture’; he maintained that scientists can’t read and that ‘humanists’ can’t understand even simple scientific concepts such as the second law of thermodynamics. Leavis’ answer was perhaps no more ill-mannered and shot with sour irrelevancies than Snow’s original lecture, brashly in favour of scientific culture in the interests of human survival, was ill-argued. The kernel of the dispute may be found, in a civilised form, in T. H. Huxley, *A Liberal Education and where to Find It* (1868) and *Science and Culture* (1881), and in Matthew Arnold’s answer, *Literature and Science* (1882). A. N. Whitehead’s *Science and the Modern World* (1927) is a brilliant and reconciliatory essay by a truly distinguished mind. (Seymour-Smith 1988, p. 878)

Notwithstanding these criticisms, it is Snow’s paper that has served in recent decades to focus this long-standing difference of views about the intellectual context of science.

First, while Snow’s use of the term *culture* can be interpreted broadly, particularly considering externalist critiques, it is the intellectual context that is the basis of the debate: that one set of ideas, or one conceptual framework, is taken as evident and true by some, but is inaccessible to others. Bronowski (1978) has interpreted this as a debate clearly about intellectual contexts, as ‘an old way of thinking and a new way of thinking’ (p. 4). He argued that the Scientific Revolution marked a profound revolution in the way of thinking, that is, it was an intellectual revolution. Moreover, he sees this as creating an intellectual imperative because humanity is confronted with having to use this new way of thinking, presumably because to fail to do so is to make do with a demonstrably inferior mode of thinking. He criticised Snow (1969) for presuming that teaching scientific developments, such as the second law of thermodynamics or molecular biology, to humanities students can bridge the gap between the two cultures of thinking. While there is a need for ‘all those literary boys’ to increase their scientific literacy, Bronowski argues
that scientists have a responsibility both to construct this whole human outlook - a view of humanity and Nature that is based on a scientific world view - and to communicate it:

[S]cientists bear a heavy and, in my view, an increasing responsibility from now on, for exhibiting the human implications not merely of what they do, but of their way of thinking. And if you want an alternative title you could substitute 'the scientific way of thinking is a human way of thinking'; and it is becoming for us the only human way which we can treat as a unifying discipline. (Bronowski 1987, p. 5)

Bronowski argues that it is not sufficient for the two groups to share their ideas - their conceptual frameworks - because the logical coherence of scientific knowledge separates it from other types of knowledge. In the terminology of the present thesis, scientific knowledge has a distinct intellectual context, which is mainly an internalist notion.

Secondly, Snow's two cultures can be interpreted also as the differences between the intellectual contexts of particular scientific expertise and any other intellectual context. For example, Ravetz (1971) points to the increasing specialisation of the intellectual context of most scientists, although the degree of specialisation varies. This means that scientists, as their specialisations increasingly narrow, are correspondingly less able to make informed judgements about claims beyond their own specialisation, including other areas of science. That is, different intellectual contexts - specialist knowledge structures and contents - within 'science', exist not only between but within fields:

It might seem that the group of people whose view of science is the most important and valid are the working research scientists themselves. But although research is at the centre of scientific activity, it remains as one very specialised part of a large and complex whole. The experience of the research worker will, in its own way, be as specialised as that of the student. His task is to achieve new results in a special field; even if he teaches part-time (as at a university) there will usually be little or no connection between the new results he is creating and the established knowledge which he is passing on. Also, unless he is already in a position of seniority and responsibility, he will have little involvement in the work which requires him to see his own efforts in the context of the field as a whole, making the judgements and decisions which determine the directions of future research. (Ravetz 1971, p. 16)

Thus Ravetz argues that the more specialised the work of the individual researcher, the more restricted the intellectual context. In this way, the intellectual context is not only removed from the 'lay' public, including the community of arts intellectuals, but from other scientists whose work is also, but differently, specialised.

Thirdly, Snow's characterisation, among others, has been used as an indicator of the (then) current understandings or characterisations of science, from which new and hopefully better characterisations could be developed. For example, Edge (1995, p. 8) takes the two cultures debate, 'sparked by C. P. Snow', and the parallel developments in science policy, to be characterisations of science as a unique and undifferentiated entity:
It was common to hear talk of a 'scientific culture', objective and hard-nosed, contrasted with a 'humane culture', which consisted (presumably) of everything else, and was characterised by a regard for subjective feelings and values. (Edge 1995, p. 8)

This is a broader notion of context than strictly intellectual, although the distinction is clear between knowledge characterised as either objective or subjective. Also, Snow and others characterised the cultures as two fairly undifferentiated entities: a scientific culture rather than cultures, and likewise a single, undifferentiated human culture. Edge traces the effect of the two cultures debate to calls to reform science education by 'humanising' and 'contextualising' it, and indeed this tradition is part of the curriculum background of the present thesis. Edge notes that much of this tradition was the critical scholarship that emerged in STS and SSK (sociology of scientific knowledge) fields, but the present paper includes also shifts in other fields such as HPS and linguistics. For example, Bowden (1995) has argued that Snow's two cultures influenced developments of STS methodologies. Traditional histories focussed on the development of particular ideas or artefacts, and in so doing distorted the interpretation of problem-solving in real contexts. For example, the design of an ocean sewage outfall might be construed traditionally as the solution of a bounded problem of sewage disposal. An alternative would be to construe the design as a choice or tradeoff between competing solutions in a wider context, arising instead from a discourse of problem understanding and choice:

In short, this viewpoint attempted to replace the authority of technical solutions with human values and the related issues of ethics and political choice. (Bowden 1995, p. 70)

That is, the two cultures debate contributed to broadening the notion of scientific context, from only intellectual to include other contexts. Bowden notes that the strengthening of free-market ideologies and policies in the 1980s served to check and to counter many initiatives seeking to politicise science based on this critique.

**Auxiliary statements**

The intellectual context of a theory is given in its theoretical statements, at least in the verificationist RV and Popper's falsificationist alternative (Boyd 1991a, pp. 7, 11). This arises because these views distinguish all non logical terms in scientific theories as being observational terms or theoretical terms:

The initial verificationist conception identified the cognitive content of a theory with the set of observational consequences deducible from the theory alone. (Boyd 1991a, p. 7)

However, Duhem and others have argued that the cognitive claims of a theory cannot arise from the statements of that theory alone because they rely on the theoretical statements of any number of background or auxiliary theories. This is a strong criticism of falsificationism: that it may be impossible to decisively refute or falsify a theoretical
claim because these auxiliary statements would also have to be identified, tested and falsified. It is also a chief argument for the theory-dependence of observations:

[T]he import of a theory depends both on its own theoretical structure and on the theoretical structures of the background theories available as auxiliary hypotheses.

Scientific methods for employing theories in making observational predictions are thus theory-dependent methods: the result of their applications depends on the theoretical structure of the theories in question. It is an important fact, now universally accepted, that many or all of the central methods of science are theory-dependent. This theory-dependence of method was initially surprising for philosophers attracted to logical empiricism ... (Boyd 1991a, pp. 7-8)

Boyd’s comment about universal acceptance needs some qualification, since he points out that while falsificationism is no longer influential within HPS (nor STS), it remains influential among philosophically-inclined scientists, ‘perhaps because of its apparent commitment to an antidogmatic conception of scientific inquiry’ (Boyd 1991a, p. 11). While Popper agrees that theoretical and observational terms are theory-laden, he holds that one can make straightforward observation statements of ‘publicly observable material objects’, resulting in simple observation statements that are testable (Suppe 1979, p. 170). Thus while the appeal of falsification is recognised as a pragmatic criterion for practising scientists, it does not address the wider intellectual context found in auxiliary statements.

Other characteristics of the intellectual context of science

Although discussed in later chapters, some final points about intellectual context should be mentioned here. First, the body of scientific knowledge - the framework of concepts and understandings - is massive and rapidly increasing, and its total comprehension is well beyond the capacity of any individual. Secondly, this knowledge is fundamentally linked to experimental and reasoning activities, and with criteria associated with a belief system, that give science knowledge a special status in society: on the one hand it is authoritative because it is empirical and subject to experimental test and review, and on the other it is tentative in a special sense, for the same reasons. The status of science knowledge in society is taken up in the following section on socio-cultural contexts.
1.6 Socio-cultural contexts of science

The discussion of e/i debates touched on notions of socio-cultural contexts. This term and its root terms, society and culture, are variously interpreted in an immense sociological literature and, particularly with society and culture, are also used in general, non-academic senses. As commonly used, society is taken generally to mean ‘a body of individuals living together as members of a community’ (The Macquarie Dictionary). However, it can also be taken to mean more than just individuals, to include the practices and patterns of interactions between them, as in an ecological sense:

Society:
(12) (Ecology) A closely integrated grouping of organisms in the same species held together by mutual dependence and showing division of labour. (The Macquarie Dictionary)

Accordingly, the present thesis interprets society generally, as the body of individuals living together, particularly its origin, development, organisation and functioning, as analysed and described in the field of sociology. Culture is also interpreted generally, as the cumulative ways a group of people lives and transmits these ways of living between generations:

Culture:
(Sociology) The sum total of ways of living built up by a group of human beings, which is transmitted from one generation to another. (The Macquarie Dictionary)

The following definition of culture provides a useful indication of the possible contextual factors from a sociological analysis:

[Culture is the] ‘social heritage’ of a community: the total body of material artefacts (tools, weapons, houses, places of work, worship, government, recreation, works of art, etc.), of collective mental and spiritual ‘artefacts’ (systems of symbols, ideas, beliefs, aesthetic perceptions, values, etc.), and of distinctive forms of behaviour (institutions, groupings, rituals, modes of organisation, etc.) created by a people (sometimes deliberately, sometimes through unforeseen interconnections and consequences) in their ongoing activities within their particular life-conditions, and (though undergoing kinds and degrees of change) transmitted from generation to generation. (Fletcher 1988, p. 195)

Thus a strong externalism holds that the material and mental artefacts and the behaviours of scientists are merely artefacts and behaviours within the larger society. More moderate variants of externalism would hold that the artefacts and behaviours of the larger society contribute to science to varying degrees, depending on the viewpoint of the analysis. Characterisations of science by socio-cultural context draw on many interpretations of culture and subculture; they illustrate the complete spectrum of e/i characterisations. They may focus, for example, on sciences as subcultures; subcultures within sciences; or the influence of or effect on particular groupings of people or society at large.
a) **Science as part of a larger socio-cultural context**

**Religion and science**

The relationship between the Christian church and the western European scientific tradition provides many examples commonly given as influences of the socio-cultural context on science. For example, science histories commonly characterise Aristotelian science partly by its relationship to mediaeval theology and the Christian church (Singer 1959, p. 54). The early and mediaeval Christian church opposed certain doctrines supported by the followers of Democritus and Epicurus, who argued for an atomic view of matter and denied the centrality of God (or gods) in human existence. The Church instead supported Aristotle's cosmology, in which God is the highest Cause, the unmoved Mover, as the most viable alternative (Tarnas 1991, pp. 64-77). Aristotle's view that matter is continuous was central to his cosmology, just as Democritus' atomism was central to the Epicureans' view; atomism therefore remained precluded from widespread scholarly attention for several centuries.

Aristotelian science and mediaeval Christian theology did not completely agree, however, as with the concept of infinity:

> The finiteness of the universe both in space and time became necessary to all the theological systems of the Middle Ages and notably that of the Western Church. It was effectively unquestioned till the time of Bruno (died 1600). Thus Aristotle himself could not be completely accepted. The philosophical return to the conception of a universe infinite both in space and time is a landmark in the history of science. (Singer 1959, p. 55)

Debate over God's relation to the universe also formed part of the flux of ideas that emerged in seventeenth century. That is, theological views formed part of arguments between the competing ontological views that emerged during that time. For example, René Descartes (1596-1650) proposed an account of an essentially ordered universe that reflected its divine order, in which the motion in the universe is conserved from the initial motion given by God. The Cambridge Platonists Henry More (1614-87) and Ralph Cudworth (1617-88) objected that Descartes excluded God from the world, and instead proposed intermediary principles by which God intervenes in the working of the universe. For Nicolas Malebranche (1638-1715), God directly caused all activity in the universe. Thomas Burnet (1635-1715) and William Whiston (1667-1752) sought to develop a 'sacred physics' that explained biblical events like the Deluge by physical law, such as the near passage of a comet. Isaac Newton (1642-1727) rejected these views and argued that the Universe is essentially unstable, needing periodic divine intervention to correct it. In turn, Leibniz (1646-1716) rejected Newton's idea of an imperfect world needing God's intervention, and argued instead for a perfect universe and transcendent God. These debates, essentially between a view of an orderly world whose design was evidence of creation by a supremely wise God and a view of an active world disrupted...
miraculously by God, continued into the eighteenth century. By the nineteenth century the
debate narrowed to ‘a discussion of the physical development of an orderly universe
through time’ (Schaffer 1983, p. 169). Thus Immanuel Kant (1724-1804) removed the
necessity for invoking God in epistemological argument, and Pierre Simon de Laplace
(1749-1827) demonstrated that the Solar System was stable over time, thus removing
Newton’s necessity for divine intervention. The positivist tradition that followed from
Laplace and others also separated God from naturalistic arguments.

Economic, political and military contexts

Argument about socio-cultural contexts of science is less concerned now with
religious views than with economic, political and military issues. Redner (1987)
characterises a fundamentally different science emerging in the twentieth century by a
complex of different contextual factors, especially economic, political and military. For
example, he quotes from the valedictory address of President Eisenhower of the USA,
the influential twentieth-century militarist and politician:

Today the solitary inventor, tinkering in his shop, has been overshadowed by
task forces of scientists in laboratories and testing fields. In the same fashion,
the free university, historically the fountainhead of free ideas and scientific
discovery, has experienced a revolution in the conduct of research. Partly
because of the huge costs involved, a government contract becomes virtually a
substitute for intellectual curiosity. (Eisenhower 1961, 1038, as quoted in
Redner 1987, p. 15).

These remarks directly confront the popular image of solitary, intellectual, curiosity-
driven scientific activity untainted by worldly contexts with a more pragmatic and
utilitarian characterisation that clearly entails a broader notion of context. Ravetz (1971)
was influential in raising awareness of the ‘technocratic conception of science’ becoming
a more useful characterisation than science as the pursuit of truth:

The obsolescence of the conception of science as the pursuit of truth results from
several changes in the social activity of science. First, the heavy warfare with
‘theology and metaphysics’ is over ... This is not so much because of the
undoubted victory of science over its ancient contenders as for the deeper reason
that the conclusions of natural science are no longer ideologically sensitive.
What people, either the masses or the educated, believe about the inanimate
universe or the biological aspects of humanity is not relevant to the stability of
society, as it was once thought to be. The focus of sensitivity is now in the
social sciences; and the techniques of control by those in authority vary in
subtlety in accordance with local requirements and traditions ... Also, the
experience of modern scientists in their work, seeing the rapid rate of
obsolescence of scientific results, makes the vision of the pursuit of truth not so
much wrong as irrelevant. But, more important, the attention of the general
educated public ... is now on the visible triumph of technology based on applied
science. Applied science has now become the basic means of production in a
modern economy. The prosperity, and economic independence, of a firm or of a
nation does not rest so much in its existing factories as in the ‘research and
development’ laboratories, where the industry of the future is being created and
the competition of the future is being met. Thus, industry has been penetrated by
science. (Ravetz 1971, pp. 20-21)
In this passage, and his ensuing argument, Ravetz characterises science by industrial-economic context, using several key issues. These are: we now recognise examples of industrial-economic contexts from at least the Scientific Revolution; industrial-economic links with science are now recognised 'by those who plan the future of our societies' (Ravetz 1971, p. 21); science is increasingly linked with technology; and the technocratic view of science, as with so many characterisations, is flawed. Each is expanded in the following paragraphs.

**There are examples of industrial-economic contexts in the history of science**

First, industrial-economic contexts of science before the twentieth century received relatively little attention until around the time of the second world war (Ravetz 1971, p. 22). For example, Zilsel (1942) has argued that modern science emerged in Europe due to a freeing up of conceptual resources that arose, in turn, from the socio-economic changes that accompanied the rise of capitalism. Briefly, he argued that the discrete social strata of late mediaeval Europe fragmented the intellectual resources of society: university scholars and secular humanists held the expertise in formal and systematic rationality, logic and mathematics, while the artisans held the empirical expertise in experiment, observation and causal thinking. These social strata were distinct until the emergence of cities as centres of political and economic freedom, in which the emerging capitalism drove the breaking down of these traditional social divisions (Shapin 1983b, p. 450).

**Policy makers recognise the interrelationships between science, industry and economics**

Secondly, the recognition of the significance of interrelationships between science, industry and economics (therefore also government) has resulted in characterisations of science by parties not traditionally recognised for their scientific or metascientific credentials. Notably, these parties include politicians, public servants and company executives who are more likely to have qualifications in law, accountancy or economics than in science or technology (Ravetz 1971; Redner 1987; Cozzens & Woodhouse 1995). It is true that government policies and position papers draw on scientific and metascientific expertise, but it is significant that these policies and papers are written within and evaluated in terms of policy frameworks determined by governments and other policy stakeholders. For example, in the late 1980s and early 1990s the Australian Government sought to develop science and technology policy partly in the context of innovation and technology transfer to industry, as part of its policy of economic reform:

> The relationship between science and technology effort and economic growth including the role of innovation in the growth process is important in national policy considerations. Indicators based on R&D have made an essential contribution to assessment of the health of the national science and innovation system and have helped guide the decisions of policy-makers. (Department of Industry, Science and Technology 1994, p. 1)
To ensure that the Government has a sound basis on which to make policy decisions to maintain a strong science base and facilitate increased innovation, the Division delivers advice concerning national science and technology policies. During 1994-95 three publications were released aimed at providing a further understanding and awareness of the characteristics, resourcing and spread of innovation and science within Australia. [These are] The Pace of Change - Technology Uptake and Enterprise Improvement ... Australian Science and Innovation Resources Brief 1994 ... [and] Innovate Australia - the Pace of Change. (Department of Industry, Science and Technology 1995, p. 132)

While the Resources Brief presented a range of indicators, including allocation of funds, numbers of science research students, and so forth, it is clear from the report extract above and even the title of the department - Industry, Science and Technology - that the government emphasises particular characteristics of science that relate more to broader political and economic policy factors than to cognitive or logistical factors internal to science communities or disciplines.

Science and technology are often associated, but their differences are not uniformly agreed

Thirdly, there has been increasing interest in the distinctions and relationships between science and technology. The characterisation of technology as applied science had been dismissed as an academic concept by the 1970s, at least in the STS literature, but the relationship between science and technology remains unresolved (Bijker 1995, p. 240). We have noted above that government and industrial policy in Australia explicitly links science and technology in addressing the contribution of research and development activity to the economic performance of Australia. Ravetz (1971, p. 21) has argued earlier that the view of science as a ‘basic factor of production’ - the technocratic view - is a ‘simplified and vulgarised’ form of Francis Bacon’s equation of knowledge and power, and has received considerable attention particularly from Marxist historians:

Even in the nineteenth century, ‘science’ was given much credit for the advances in technology which so dramatically transformed life in the advanced nations; and so it is the widespread adoption of this view, rather than the insight itself, which is characteristic of the present age. (Ravetz 1971, p. 21)

There are various indicators that support such a view. Redner (1987, pp. 66-84) has characterised a fundamentally different science emerging in the twentieth century, as mentioned earlier, partly on the basis of the convergence of several historical developments concerning technology and science. These are the progressive application of scientific theory to technology (the ‘scientification of technology’), a tendency towards problem-solving, and a fundamental change in the role of technology in science (the ‘technification of science’).
Thus the limited examples of scientific knowledge being applied to technology up into the nineteenth century were mostly in instrumentation. This only changed when more complex technologies developed:

Proper scientification of technology began when the industrial processes themselves, at certain advanced stages of their development, demanded scientific knowledge, and, simultaneously, when scientific knowledge became the source of new industrial processes and technical developments, as in the electrical and chemical industries. (Redner 1987, p. 67)

The place of problem-solving in science has changed. Redner has argued that while it had a traditional role peripheral to the main goal of developing theories and laws, in the twentieth century it came to have a central role in creating new knowledge (1987, pp. 80-81). Thus much contemporary scientific activity is established precisely in order to solve problems, as in nuclear physics and molecular genetics:

The concentration on problem-solving in [molecular genetics], as in any other science, came to exercise an extremely wide-ranging influence on the whole character of the scientific undertaking, affecting the general goals of the science, its specific research programs and the methods and techniques employed. As Yoxen (1982) points out, the attitude of molecular biologists to life changed as the result of the problem-solving impetus ...

A concentration on solvable problems in turn affects and is affected by all the academic political aspects of science in a vicious circle of cumulative causation. The need for publishable results means that only those problems are tackled which promise to be solvable with the available techniques in the period of time for which the funding is allocated ...

Problem-solving of this kind pushes science ever further in the direction of technology. Any distinction between a scientific research laboratory and a technical institute disappears. Both specialise in solving useful problems on contract. Thus once molecular biology had gone in the direction of genetic engineering it assumed the problem-solving propensities of a technological enterprise. (Redner 1987, pp. 82-3)

Redner argues that technified, problem-solving approaches render the science less likely to make any fundamental breakthroughs in uncovering the unknown, a situation observed in most of physics, chemistry and systematic biology. He notes an even stronger ('almost pathological') situation in the social sciences, where this tendency has distorted the identification of and approach to significant social issues, sometimes counter-productively (p. 84). Technification, the third of Redner's twentieth century developments, refers to changes in the role of technology, rather than to economic or political contexts, so it is not directly relevant here.

Technocratic views of science are popular but flawed

Fourthly, technocratic characterisations of science have strengths and flaws. From the foregoing discussion it is clear that governments and industry benefit from the efficient and timely use of scientific knowledge and skills. However, Ravetz (1971, pp. 21ff) cautioned that the strategic support of science by governments and industry has distorted the operation of science. Technification led to increased specialisation of labour,
as in most industrial enterprises, which affected not only the work of individual researchers, but increased the need for administrative and executive activity. Also, strategic economic funding, usually by clearly specified, short-term contracts, has displaced much of the traditional funding for science, eroding support for science not characterised by expected and specified short-term outcomes. Technocratic approaches to science also affect science in more fundamental ways:

[T]he assimilation of the production of scientific results to the production of material goods can be dangerous, and indeed destructive to science itself. For producing worthwhile scientific knowledge is quite different from producing an acceptable market commodity, like soap. Scientific knowledge cannot be mass-produced by machines tended by semi-skilled labour. Research is a craft activity, of a very specialised and delicate sort. (Ravetz 1971, p. 22)

Ravetz argued that technocratic approaches tend to work against traditional characterisations of quality control of the sciences. They tend to fragment communities of scholars who share a common knowledge base and ethos, and weaken the traditional means of quality control, which depend on individual commitment and integrity. Redner extended this argument to posit the emergence of a World science in the twentieth century that is characterised partly by its tendency to technification.

In summary, these characterisations of science in relation to technology are examples where science is characterised by the socio-cultural contexts of which it is part. As we have seen, a moderate externalism acknowledge these contexts even if as deleterious influences on the ‘proper’ workings of ‘pure’ science. This is consistent with views that see a clear distinction between pure and applied sciences. However, as we have also seen, some views argue a stronger externalism by holding that these socio-cultural factors are inextricably linked to, and fundamentally influence the outcomes of, science. These views typically reject normative views of science, that seek to describe an idealised state, in favour of descriptive views that describe science as it is actually practiced. As we will see time and again in this thesis, recent metascientific analyses such as these invariably present complex characterisations of science.

(b) Science as a subculture and subcultures within science

Science is characterised by socio-cultural contexts not only in the sense of larger contexts, but also in the sense of subcultures within scientific cultures.

Scientific paradigms

The contextual term paradigm, from Thomas Kuhn (1962), is commonplace in metascientific thinking and, despite its declining influence in HPS, has spread to other fields and even to general use. Kuhn proposed initially that a paradigm is the general set of assumptions, laws and activities adopted by a community of scientists: the ‘accepted examples of actual scientific practice - examples which include law, theory, application, and instrumentation together - [that] provide models from which spring particular
Appendix B.1: Context

coherent traditions of scientific research’ (Kuhn 1962 p. 10, quoted in Suppe 1979, p. 136).

Kuhn characterised mature science as taking place within two main contexts: normal science done within a paradigm, and revolutionary science when a new paradigm replaces an existing one. The early, formative years of a science discipline are characterised by much debate and fluidity of ideas, and there is no accepted paradigm, which resembles more usual characterisations of the arts and most of the social sciences (Kuhn 1963, in Kuhn 1972 p. 87). Since then, several commentators and Kuhn himself have come to regard this account as having become something of a doctrine for all purposes. That is, the notion of a paradigm has been interpreted widely in the literature to support a variety of incompatible arguments (Suppe 1979, p. 137). In response to criticism that the term was ambiguous, Kuhn instead distinguished a general meaning, as the disciplinary matrix, and a narrower sense, as the exemplar (Suppe 1979). Despite these criticisms, the notion of a paradigm remains commonplace in metascientific thinking and more broadly in other fields, thus representing a strong point of characterisation by context. The intellectual context is clearly central to the notion of a paradigm - scientists doing normal science work within an accepted framework of concepts, or a conceptual perspective - but a paradigm, by whichever definition, is a much broader notion of context than merely the cognitive. Because of the increasingly specialised character of science, different cognitive contexts form part of the different paradigms that characterise the different sciences; that is, different subcultures.

Weltanschauungen characterisations

A number of metascientific theories arose from critiques of the RV arguing that scientific theories can only be understood from within a Weltanschauungen or Lebenswelt, which is the general notion of a conceptual perspective (Suppe 1979, pp. 125ff). Following Reichenbach’s distinction between the contexts of discovery and justification, most proponents of the RV argued that epistemology is concerned only with the context of justification, because it can be subjected to rational reconstruction. Thus theories are confirmed or disconfirmed by judgements passed on their final version, when they are either further confirmed or (following Popper) are falsified. Weltanschauungen theorists, on the other hand, argue that our experiences of the world are shaped by our language and the concepts we use to determine which questions to ask and which answers to accept. (The present thesis argues that these are part of the belief system of the observer, a point addressed in the companion chapter on belief systems). They also argue that, contrary to the positivists’ account, theories are rarely rejected when they fail to pass a test, but are modified according to epistemic factors of science. To account for this, theories must be analysed to determine ‘the epistemic factors governing the discovery, development, and acceptance or rejection of theories’ (Suppe 1979, p. 126). That is,
theories can only be understood by accounting for the conceptual perspective or Weltanschauungen:

Full epistemic understanding of scientific theories could only be had by seeing the dynamics of theory development, the acceptance or rejection of the theories, the choosing of which experiments to perform, and so on. To understand a theory was to understand its use and development. (Suppe 1979, p. 126)

They therefore reject Reichenbach's dismissal of the context of discovery. Weltanschauungen analyses characterise science as a social enterprise in which the participants share a common language, methodology, conceptual framework, and so on. The present thesis interprets this as meaning the participants share a common context: shared structures, purposes, knowledges, belief systems and activities.

Several of the better known Weltanschauungen characterisations, which feature in most introductory metascientific texts published from the 1970s, present accounts of science involving this notion. In contrast to the positivist RV, Weltanschauungen analyses characterise science as involving an interplay between theory, observation, meaning and facts, as given in these three theses:

1) Observation is theory-laden: The Weltanschauungen determines or influences how one views, describes, or interprets the world; hence adherents to different theories will observe different things when they view the same phenomena.

2) Meanings are theory-dependent: The descriptive terms (both observational and theoretical) used by a science undergo a shift in meaning when incorporated into, or used in conjunction with, a theory; thus the principles of a theory help determine the meanings of the terms occurring in them, and so the meanings of such terms will vary from theory to theory; hence changes in theory result in changes of meaning.

3) Facts are theory-laden: What counts as a fact is determined by the Weltanschauungen associated with a theory; as such there is no neutral set of facts for assessing the relative adequacy of two competing theories; rather, the adequacy of a theory must be assessed according to standards set by its associated Weltanschauungen. (Suppe 1979, p. 191)

For example, Toulmin (1953, 1961) proposed that scientific theories are instrumental: they are neither true nor false but comprise laws, hypotheses and ideals of natural order that serve as rules for drawing inferences. Therefore they are judged by how fruitful they are, and the criteria for this judgement are the presumptions and ideals of natural order comprising the intellectual perspective or Weltanschauungen (Suppe 1979, pp. 127ff). Kuhn's (1962) characterisation of science has been mentioned above. Like Toulmin's account, it sees science as working within a Weltanschauungen or paradigm that develops, but whereas Toulmin sees the Weltanschauungen as evolving by adding new ideals of natural order, Kuhn sees the development of a scientific Weltanschauungen as discontinuous, and subject to extensive revision or replacement by another. Hanson (1958) argued that observations are theory-laden because they are shaped by a conceptual pattern arising partly from the meanings attached to terms and partly from the 'lawlike generalisations, hypotheses, and methodological presuppositions one holds in context'
(Suppe 1979, p. 165). While Feyerabend also holds that theories are made within a Weltanschauungen (see summary statement 113), he agrees with Popper that science grows, or should grow, by the proliferation of competing theories. Thus for Feyerabend, there should be competing Weltanschauungen:

On Feyerabend's view it is imperative that the same scientists or scientific community be able to understand and compare many radically different theories or Weltanschauungen: it would not suffice to split science into a number of competing schools, each with its own single theory or Weltanschauungen. However, when the theories involved are general theories which function as Weltanschauungen for viewing the world, it becomes questionable whether there are any persons psychologically able either to alter world views when entertaining alternative theories or to switch from one Weltanschauungen to another at will. Thus it is questionable whether his analysis is psychologically possible. (Suppe 1979, p. 180)

Weltanschauungen analyses, like other metascientific views, have their critics. While each of the views above is subject to its particular criticisms, there are also criticisms of the general Weltanschauungen approach (Suppe 1979, pp. 191ff). General criticisms can be made of each of the three central theses given above, concerning observation, meaning and objectivity. First, observation within a Weltanschauungen can be interpreted as the Weltanschauungen partly constituting the object and its properties being observed. This leads to an extreme relativism, in which each Weltanschauungen constructs its own reality. An extreme relativism is problematic because any such analysis must itself be relative. However, none of the Weltanschauungen analyses discussed relies on this view. It is therefore dismissed in favour of a more acceptable interpretation, that the objects and their properties exist independently of the Weltanschauungen, but the kind of object and property they are observed as being and having is determined partly by the Weltanschauungen. For Suppe, this is a sufficient but not necessary account of observation, because it only holds if theories influence observations and (partly) determine the Weltanschauungen; writing in 1977, he calls for further work to be done on this.

Secondly, as with the observation thesis, the thesis that the Weltanschauungen determines meanings has two possible interpretations (Suppe 1979, pp. 199-208). The stronger version, as in Feyerabend's earlier writings and Bohm, holds that the meanings of terms in a theory are determined by all the principles in the theory. This version has been subjected to severe criticisms. For example, because both predictions and observations are expressed in the same language using the same meanings, the evidence (or 'facts') used in testing a theory cannot be relevant unless they are consistent with it. Thus the testing of a theory is circular, and this version is rejected. The weaker version, as in Toulmin, Hanson and Kuhn's later writings, holds that the meanings of terms in a theory are only partly determined by the principles in the theory and that only some principles may apply to some terms. The weaker version may be defensible, but as stated
it does not support any of the Weltanschauungen analyses reviewed and, for Suppe and Shapin, is not very useful because analyses of meaning are 'of little help in understanding the workings of scientific concepts and theories' (Suppe 1979, p. 208). That is, theories cannot be fully understood as linguistic entities.

Thirdly, the objectivity thesis is also subject to a range of criticisms, but Suppe concludes that a defensible version is possible, that 'the Weltanschauungen determines which facts one can entertain, which of those facts are relevant to the adequacy or development of the theory, and which facts one is able to determine observationally' (pp. 216-7), while allowing for an independent and 'objective' reality, and the requirement of empirical support for the theory. The present thesis argues that the criteria used for making such choices are part of the belief system.

The nature of a Weltanschauungen is complex and not consistent between metascientific accounts, and the notion of how a Weltanschauungen is shared by a group of scientists is less clear. Suppe judged Weltanschauungen characterisations as failing to make the case for a necessary and causal Weltanschauungen. He concluded that the notion of a Weltanschauungen is nonetheless useful for interpreting certain aspects of science and, while still debated by philosophers of science, appearing to be less fruitful than pursuing instead semantic or linguistic analyses of science. Two decades after Suppe’s comments, the notion of a perspective or Weltanschauungen characterising science remains debated in HPS and pursued vigorously in STS analyses. Thus some versions of constructivism and some other characterisations such as Bhaskar’s scientific realism hold that contextual factors something like a Weltanschauungen partly shape our understanding of an independent reality. The following subsections address two notable examples: gender and science, and non-western European traditions of science.

(c) Science as characterised by the effect of, or the effect on, particular groupings of people

Feminist critiques of science: is the context of science masculine?

One perspective of analysis that emerged in the post-positivist critical debates in metascience was feminism. Feminist critiques seek to make clear the effect of gender on characterisations of science. As usual with aggregations of theories such as groups or fields, and especially with fields that are relatively new and growing rapidly, the notion of ‘feminist critiques of science’, or ‘gender and science’, pulls together a wide variety of views and approaches. These include differences in conceptions of feminism, of the boundaries and relationships between science and other fields, and of what the matters of interest are (Keller 1995; Gieryn 1995). Nonetheless, there is sufficient structure and pattern to discern some trends and potential trends of characterisation. This is outlined in the following paragraphs, drawing chiefly on Keller’s and Gieryn’s reviews of the field.
Despite variations in feminist critiques of science, they often begin from an interest in the relationships between gender, objectivity, and science:

The historically pervasive association between masculine and objective, more specifically between masculine and scientific, is a topic that academic critics resist taking seriously ... The virtual silence of at least the nonfeminist academic community on this subject suggests that the association of masculinity with scientific thought has the status of a myth which either cannot or should not be examined seriously. It has simultaneously the air of being 'self-evident' and 'nonsensical' - the former by virtue of existing in the realm of common knowledge (that is, everyone knows it), and the latter by virtue of lying outside the realm of formal knowledge, indeed conflicting with our image of science as emotionally and sexually neutral ... (Keller 1978, quoted in Keller 1995, p. 81)

For Keller and others, myths about science should be investigated to discern whatever realities and influences they indicate, rather than dismissed as ineffectual fictions. The links between masculinity and objectivity are therefore overdue for analysis whatever is the initial view:

The principal point I wish to emphasise is that the role of gender ideology is but one aspect of the constitutive role of language, culture, and ideology in the construction of science, and hence, though the roots of such analyses have been and must continue to lie in feminist theory, I take their place in science studies to be just one part of that more general inquiry. I suggest that work in this area not only has raised novel kinds of questions for historians, philosophers and sociologists but also offers some more novel models of and sites for analysis that might even be of use to those who are not women, who may not even be gendered, and who don’t necessarily think of themselves as feminists. (Keller 1995, p. 86)

Feminist critiques argue that both a gendered vocabulary and wider cultural factors have wide-reaching implications for our understanding of, and hence characterisations of, science, and these implications should be investigated.

Three issues of characterisation arise from studies in gender and science (Keller pp. 86ff, and Gieryn pp. 420ff). First is the involvement of women in science. Analyses of women in science show that men have been, and are, far more highly represented in science, particularly in certain fields, and ‘especially so at the highest levels of honour and power’ (Gieryn p. 420). These studies explicitly concern characterisations of science and their effects, both in marginalising the contributions of women, and in discouraging the involvement of women:

Londa Schiebinger (1989) offers the well-known example of midwifery - and less familiar ones of medical cookery, home economics, and debates in Parisian salons - to illustrate how some investigative, discovering, and practically useful activities dominated or controlled by women get defined as prescience, superstition, applied arts, or the humanities while boundaries of real science get laid down in their professionalisation. (Gieryn 1995, p. 421)

There is a correlation, then, between changes in the scientific status of certain activities over time, and gender. This is compounded by the institutionalisation of science over time, in which the scope of scientific activity reduced to what took place in institutions,
while women's involvement in institutions was marginal. The milder argument from these studies is that science has been, and is, characterised by men, especially in influential positions. The stronger argument is that the dominance of men in science has influenced other characteristics of science, such as the relative status and support of different scientific endeavours, and even the construction and practice of science itself. This leads to the second and third issues in the interaction between gender and science.

The second focus of interest is scientific constructions of sexual difference. Gieryn (p. 422, citing Rossiter 1982, and Schiebinger 1989) argues that 'demarcations' between notions of male and female 'co-evolved' with demarcations between scientific and other knowledges. Thus objectivity, reason and mind came to be seen (that is, characterised) as male, while subjectivity, feeling and Nature came to be seen as female. The characterisation of science as the exemplar of the impersonal, the rational and the general fitted the construction of maleness and not femaleness:

Women were now constructed to be inappropriate for science, and (not by accident) science was trotted out to lend its growing authority to that myth. Biological studies of sex differences (especially in the late nineteenth and early twentieth centuries) discovered in the female body - brain, skull, pelvis - a machine less efficient for the intellectual demands of science than for mothering (Schiebinger 1989). Harding (1991) concludes that 'women know very well that knowledge from the natural sciences has been used in the interest of our domination and not our liberation'. (Gieryn 1995, p. 422)

Moreover, continues Gieryn, these gendered characterisations have affected the involvement of women in science: they have made science less appealing and more formidable as a career choice for girls, they have legitimised the relegation of women in science to subordinate activities removed from the vanguard of research, and they have legitimised the relegation of women scientists to 'generally lukewarm-to-cold scientific fields for which their feminine talents were thought to be especially appropriate: "home economics, botany, and child psychology"' (Gieryn p. 422).

The third focus of interest is the use of gender in scientific constructions of subjects and objects (Keller 1995, pp. 86ff). This is the most significant for the present thesis. Critics of characterisations linking gender and science might retort to the first point that the involvement of women in science is an interesting social and personnel issue, but does not concern science itself. To the second they might reply with some boundary work: that the use of science in constructing sexual differences was an example of bad science, and bad science is eventually found out and rejected by doing more science, not less. Such a critique, however, must concede that the third point concerns science itself. (Of course, regardless of their reception, the first two points are characterisations of science in the literature, and if accepted they support the third point). There is a range of feminist analyses concerning 'the implications of gendered vocabulary in scientific discourse' (Keller 1995, pp. 86-7), ranging from reading scientific texts to more fundamental issues such as the scientific representation of Nature:
In all of these examples, metaphors of gender can be seen to work, as social images in science invariably do, in two dimensions: They import social expectations into our representations of nature and, by so doing, they simultaneously serve to reify (or naturalise) cultural beliefs and practices. Although the dynamics of these two processes are almost surely inextricable, many feminists focus on the latter, emphasising their effects (usually negative) on women; here my focus will be on the former, on their influence on the course of scientific research. (Keller 1995, p. 87)

Analyses of past and current research in reproductive and developmental biology show how scientific discourses can be gendered and not neutral. First, notions of gender are extrapolated into ‘extraphysical properties’ such as active/passive and independent/dependent, as discussed above. Then these properties are ascribed to parts of the whole, such as subprocesses. Perhaps the paradigm example is the traditional characterisation of the sperm cell as ‘active’ and able to ‘penetrate’ the egg, and the egg cell as merely ‘drifting’ and being ‘penetrated’. Keller’s argument is that no mechanism for the activity of the egg was postulated because none was assumed to exist. Recent research, however, emphasises the mutual activity of the two gametes, which Keller interprets as reflecting a shift in metaphor (pp. 87-8). There are similar accounts of biological understandings of sex determination and of the relationship between the cytoplasm and nucleus in the cell. More subtle uses of metaphor in scientific explanations, particularly gendered metaphors, include the debate between genetic determinism and organising (or ‘master’) molecules as explanations in developmental biology. Keller observes that part of such debates is concern over whether particular explanations are being used to serve ideological purposes:

... [F]eminist arguments for the use of gendered metaphors to (a) legitimate an agenda for scientific knowledge aimed at the domination of nature and (b) facilitate the projection of that agenda onto explanatory models for natural phenomena are often read in caricature, to approximate a kind of conspiracy theory. For just this reason, it is necessary to clearly emphasise what is not being claimed in these analyses. Of particular importance is the fact that no causal claims are being made, either for gender (hardly the only source of productive metaphors for science) or for language more generally. Metaphors - of gender or anything else - clearly do not, by themselves, drive the production of scientific knowledge; nor is language, by itself, capable of conjuring material effects. But language does guide the human activities necessary to the construction of material effects. (Keller 1995, p. 90)

Thus for Keller gendered metaphors in science are but an example of the larger issue of the use of metaphor generally in science. She calls for further attention to the effect of metaphors on mind-sets and the possibilities of alternative mind-sets11.

11 The present thesis addresses particular issues arising from the use of language and metaphors respectively in the companion chapters on structure and belief system, and in Appendices B.2 and B.4.
The present thesis focuses on the western European scientific tradition, as defined in section 1.4 above. The reason for this focus, as mentioned earlier, is to address the concerns of science curriculum stakeholders: it is imperative that curriculum stakeholders understand that the proposed analysis applies to the scientific tradition notionally addressed by the science curriculum. However, the question of science in non-western contexts arises and must be addressed.

Many accounts of the western European scientific tradition characterise it in part by comparison with other, non-western, cultures; therefore, some cross-references to non-western cultures should be mentioned as examples of characterisations mainly by context. For example, it is traditionally assumed that western European science alone is universal and acultural:

By and large, past cross-cultural work has taken Western 'rationality' and 'scientificity' as the benchmark criteria by which other culture's knowledges should be evaluated. So-called traditional knowledge systems of indigenous peoples have frequently been portrayed as closed, pragmatic, utilitarian, value laden, context dependent, and so on, implying that they cannot have the same authority and credibility as science because their localness restricts them to the social and cultural circumstances of their production. These were accounts of dichotomy where the great divide in knowledge systems coincided with the great divide between societies that are powerful and those that are not. Here was a satisfying explanation of the relation between knowledge and power. (Watson-Verran & Turnbull 1995, pp. 115-6)

Comparisons of this sort, that contrast fundamental assumptions, beliefs, and so on, raise significant questions about applying the characteristics of one culture to interpret the characteristics of another, and by what characteristics (serving as criteria) the two are compared. These are critical issues for the present thesis when it argues that the proposed six-dimensional characterisation of science is a framework that enables useful comparisons between cultures as well as within. In claiming to be well-grounded in a broad selection of the metascientific literature, the present thesis acknowledges the diversity of views and emphases. This diversity of focus ranges from recognising the evident successes of the Western European scientific tradition, to seeking be sensitive to the successes of other traditions, as we will see.

The term science denotes a western European concept

First, there are fundamental difficulties in judging other cultures by the criteria of western science: what is regarded in the West as science may not only be absent in other contexts but blind us to other ways of thinking and conceptualising the cosmos. The very use of the word science in non-western contexts should be made with caution, because it entails applying a concept that describes the western European experience to those in other cultures. For example, Ronan (1982, p. 8) takes a broad view of what is science:
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'science is something that has appeared in every culture on Earth; it has grown naturally out of man's [sic] innate curiosity about the world in which he finds himself'. On the other hand, Ågren (1983, p. 65) cautions: 'The use of the Latin word science in a non-Western setting has risks'. Applying the characteristics by which Western European science is understood to a different cultural context runs the real risk of failing to appreciate the characteristics of the other culture. To recognise the inherent problems even in naming comparable, non-western, traditions with western European science, we will use the term natural philosophy, an older term in the western European tradition than science.

Criteria for characterising natural philosophies (sciences) in different cultures

The second issue in characterising natural philosophies, or sciences, across cultures is the criteria used for making such a comparison: that is, what features are used to characterise traditions in both cultures. Presumably, for any comparison to be made there must be some recognisably comparable elements which western scientists would regard as science, while at the same time acknowledging or claiming that the culture in question did not develop a tradition as we understand science. This section will give some examples from the literature that characterises differences and similarities between natural philosophies, particularly by the underlying beliefs about the cosmos (ontological beliefs) and the orientation necessary to have knowledge of it (epistemological beliefs), frameworks of knowledge, and various activities and purposes.

There is a far greater western literature on western European science than on traditions of natural philosophy in other cultures. There is some work, for example, on the achievements of the Babylonians and Egyptians, particularly as precursors to the Ionians, and of the Arabs (especially Islamic science), who kept alive the Aristotelian tradition in the Middle Ages. Likewise, there is some work on the (mainly Hindu) natural philosophy in India, especially mathematics, and in China, especially with technology. In the case of Chinese natural philosophy, what is known in the West is dominated at this stage by the scholarship of one person, Joseph Needham, and it will take some time before his scholarship - especially the effect of his Marxist interpretation - can be evaluated against a wider field or scholarship (see variously Sivin, de Solla Price and Nakayama, all in Nakayama and Sivin (eds) 1973). Even against these standards, there is far less than this amount available for many cultures. For example, among the indigenous peoples of Australia, the Pacific, the Americas and Africa, both contemporary and historical, this literature is comparatively small and only recently emerging. Some examples are given below.

The present thesis argues that its categories of characterisation apply equally well to traditions of natural inquiry in other cultural contexts, even though it was developed from literature mostly addressing the western European scientific tradition. Therefore it is a
useful means of characterising similarities and differences between traditions of natural philosophy. The basis of that argument is that the proposed categories are categories of meaning, within which an extensive selection of metascientific arguments can be placed. This gives rise to a reasonable (inductive) expectation that other views can also be described in terms of the proposed categories.

**Non-western examples in western scholarship**

The third issue in characterising science across cultures is that various groups in Western societies are showing increasing interest in non-Western traditions. One example is the increasing interest in Western societies in non-Western medicine; another is the interest in non-Western land management practices; and a third is an interest in moving beyond traditional assumptions that Western culture, including and perhaps especially Western science, are inherently and self-evidently correct and superior. In this context, some science curricula now have a broader scope than only the western European scientific tradition. Increasingly, curricula in western systems seek to broaden their scope, and curricula in non-western countries seek to address indigenous or local traditions. These matters are addressed in part 4 of the present chapter in the discussion of the curriculum implications.

Eurocentric characterisations of the sort criticised by Watson-Verran and Turnbull simultaneously characterise non-Western 'science' (mostly negatively) and Western 'science' (mostly positively). An example is accounts that attempt to explain why the Scientific Revolution occurred in Europe but not in other cultures. Some characterisations point out there was no similar explosion of ideas in China, in spite of the many pioneering developments there in science and technology up to that time:

... the perennially good talking point of why China did not have a scientific revolution and a full-scale industrial revolution like those that threw the West into dominance. Or, if you like, why was the West out of step in undergoing these curious manifestations? (de Solla Price 1973, p. 18)

The difference between science in China and Europe is often couched in a negative sense, representing the difference as a failing in China:

... the tantalising problem of cultural history, the failure of the Chinese to develop isolated rudiments of scientific feats into a self-sustaining practice of the scientific method. (Jaki 1974, pp. 31-32)

and again:

Why China lost its former lead and fell behind Europe is almost the first question that a layman asks about Chinese civilisation, a question from which sinologists tend to shrink into their separate compartments, afraid of being caught up in inconclusive generalisations. (Graham 1973, p. 45)

The 'tantalising problem' referred to by Jaki is that despite the possibility that any number of these developments could have triggered a self-sustaining tradition as in Europe, they did not. He therefore judges Francis Bacon's characterisation as inadequate because it
fails to account for the ‘failure’ of the Chinese, and instead posits a theoretical framework as a distinguishing characteristic that led to a (Western European) scientific tradition:

Printing, gunpowder, and magnets, these were the factors which in Francis Bacon’s estimate did more than anything else to usher in the age of science. It might have shocked him to learn that for all their gunpowder, magnets, and printing skill the Chinese remained hopelessly removed from the stage of sustained, systematic scientific research. They had rockets for centuries, but failed to investigate their trajectories, or to probe into the regularities of free fall. Unlike in the West, bookprinting did not lead in China to a major intellectual ferment. Although magnets were installed on Chinese ships, which formed the best navy in the world during the fourteenth and fifteenth centuries, their captains never had the urge of a Vasco de Gama, Columbus and others to circumnavigate the globe. (Jaki 1974, p. 32)

There are several problems with this Eurocentricism. First, the notion of the difference between Europe and China being somehow a failing on the part of China is probably unproductive. It is Eurocentric in that European assumptions are unquestioned and Chinese assumptions undervalued:

The pervasive recognition, characterised as postcolonialism, that the West has structured the intellectual agenda and has hidden its own presuppositions from view through the construction of the ‘other’ (see Clifford 1988; Diamond 1974; Nandy 1988; Said 1978) is nowhere more acute than in the assumption of ‘science’ as a foil against which all other knowledge should be contrasted. (Watson-Verran & Turnbull 1995, p. 137)

Nor is there any guarantee in choosing an author who is sympathetic to his/her subject. For example, Joseph Needham’s knowledge of and respect for science in China is acknowledged, yet Arthur Wright and Arthur Hummel are critical of Needham for not accounting for a fundamentally different set of attitudes and priorities displayed by the Chinese: an interest in people and society rather than Nature (Nakayama 1973, p. 35).

Secondly, characterising the difference between China and Europe as a Chinese failing is also problematic because it can become a rather hollow analysis:

The trouble is that explanations of China’s failure to attain modern science are generally no more than proofs that she was not following the route by which we arrived at it. (Graham 1973, p. 53)

That is, there is an assumption - that the present thesis interprets as part of a belief system - that the ‘proper’ and only way of developing science is the way it has developed in Western Europe. Moreover, it easily leads to the conclusion that other natural philosophies would arrive at the same result as Western European science has if they followed the same development. This conclusion results directly from the acceptance of a particular characterisation of science. It is also susceptible to a fallacy of historical interpretation:

We must glean our anticipations of the modern science of life from far and wide, from sources that their authors would not have agreed had anything significant in common. Much of what early Chinese thinkers had to say about motion, heat, and light is just as scattered. The basic concepts that they used to explore
physical phenomena are precisely yin-yang, the Five Phases, the trigram and hexagram systems of the Book of Changes, and others that used to be invoked (even by early twentieth-century Chinese thinkers) as chiefly responsible for the failure of Chinese to learn how to think scientifically.

But to place the responsibility there is to commit one of the most elementary fallacies of historical explanation, namely to present a description of what the world was like before X as though it were an explanation of why X happened so late or failed to happen at all. Since the concepts I have mentioned were the vocabulary of early scientific thought, it is as misguided to call them an impediment to modern science as to consider walking an impediment to the invention of the automobile. But that fallacy is a very tempting way out of difficulties into which we inevitably fall if we ignore the limitations of positivistic analogies and take them for full explanations. (Sivin 1973, p. xvii)

Identifying assumptions in western European science

The third issue in characterising sciences across cultures is identifying, or not, assumptions and beliefs about western science. To characterise non-Western science as ‘failing’ can divert attention from how science is characterised. The reverse strategy - to look instead at why a scientific revolution took place in Europe - can and, on Graham’s account, should be put. Probably the best known passage advocating the reverse case is from Einstein:

Development of Western Science is based on two great achievements, the invention of the formal logical system (in Euclidean geometry) by the Greek philosophers, and the discovery of the possibility to find out causal relationship by systematic experiment (Renaissance). In my opinion one has not to be astonished that the Chinese sages have not made these steps. The astonishing thing is that these discoveries were made at all. (Albert Einstein, quoted by Graham 1973, p. 50)

The present thesis argues that the character of science is multi-dimensional, and therefore to understand this significant historical (contextual) change, one must examine also the other dimensions of characterisation.

Clearly, there is a balance to be struck between a ‘hegemony of Western rationalism’ which precludes the possibility that science could be other than what it is, and an ‘unbridled cultural relativism [that] can only lead to the proliferation of [narrow interest] ghettos and dogmatic nationalism’ (Watson-Verran & Turnbull 1995, p. 138). Western European science has made very obvious successes, which need to be understood, but these successes should not blind us to recognising and understanding successes from within non-Western traditions. As a solution, Watson-Verran and Turnbull identify an intersection of ‘the social study of science with anthropology, postmodernism, feminism, postcolonialism, literary theory, geography, and environmentalism’ into which all knowledge systems can be placed (p. 115). In this context, all knowledge systems exhibit a tension between the local and the global. The global is characterised by the ‘strength of standards, generalisations, theories, and other assemblages of practices with their capacity for making connections and at the same time providing for the possibility of systematic criticism’ (p. 136). The local is characterised as
the site of both systematic practice and 'local resistance', where abutting or overlapping knowledge systems conflict and seek legitimisation through systematisation. The intersecting fields just mentioned focus on contextuality, understanding the role of social life, and on explaining knowledge outcomes that are the exception or are undetermined, but a balance must be maintained to avoid creating a new hegemony that celebrates the local and rejects the global (pp. 137-8).

Watson-Verran and Turnbull give several examples. One is the Gothic cathedrals, which 'have the appearance of the rationality, order, calculation, and uniformity that typify Western science' (p. 118), but were built without overall plans or architect supervision by successive teams of masons. Each team had their own 'local' knowledges of geometry, technique and measurement, which they applied using reproducible templates. Second, the Anasazi, a group of North American Indians who lived in the desert around 200-700 AD., built a thriving and complex society of up to 10 000, with structures including massive irrigation systems, networks of roads, and massive buildings several stories high and underground. This was enabled by systems of agriculture, storage and organising people that used knowledge and information that was developed, sustained and transmitted using (mainly) an accurate calendar, 'along with ritual, myth, poetry, and architecture' (p. 120). The calendar was based on an astronomy that exhibited characteristics of Western science, such as observational and theoretical frameworks, even though it was locally limited because only the priest had the knowledge. Similar examples of local knowledges with global characteristics include the Incas, who made similar developments to the Anasazi, but also developed a powerful system of calculation, and the Micronesians, who successfully navigated the Pacific using a powerful system of navigation that was transmitted (but locally restricted) orally.

Even analyses claiming to be culturally sensitive, such as that by Watson-Verran and Turnbull, above, need to be read with a careful eye to sensitivity. They characterised global knowledges by strong standards, generalisations, theories and systematic criticism. These are characteristics by which western European science is usually recognised, as indicated in the quoted text: *have the appearance of the rationality, order, calculation, and uniformity that typify Western science.* Thus if *global* is substituted by *Western European science*, their analysis assumes the appearance of the Western hegemony they seek to redress. Further, the analysis can veer close to being read as *these people are (unexpectedly) admirable because they are like us*. Clearly, this is not intended, but the possibility highlights the difficulty of constructing analyses which seek to be sensitive to multiple contexts. The present thesis interprets such analyses on two levels: first simply as an example of a genre of characterisation in the literature, which therefore should be included, and second as an example of analyses that identify characteristics of what Westerners agree is science in non-Western contexts, where those characteristics arose in non-European contexts.
1.7 **Human contexts of science**

Science is characterised sometimes by people as individuals rather than in groups: that it is characterised by particular professionals (scientists), or by the characteristics of individuals such as personal and psychological factors. The rejection of the context of discovery by the positivist RV meant that human contexts were not recognised as characterising science. This was certainly so while the RV dominated, and continues due to the residual influence of that view, as noted earlier. This means that, paradoxically, human contexts remain more widely acknowledged in popular media rather than in scholarly positivist characterisations of science as objective and free of human context. Human contexts are, however, the subject of attention generally in STS and in post-positivist HPS. This section will outline some analyses of human contexts in science.

**The stereotypic characterisation of the scientist**

The popular stereotype of the scientist, as used in the mass media, draws strongly on human contexts. The characterisation of the scientist as a white, older male, wearing a laboratory coat and spectacles, and a little dishevelled, is a powerful and popular image, reported in many studies including those of school children:

Although these studies have used a variety of methods ... they agree that images tend to appear in several clusters: 'devil', 'out of this world', 'wizard/genius', and 'war'.

Two early studies were a survey of high school students by Mead and Metraux (1957) and a review of comic books and other 'pop culture' items by Basalla (1976). Both identified the stereotype of white-coated, male scientists with extraordinary powers, often divorced from social responsibility. These tentative analyses have been expanded by LaFollette (1990) and Nelkin (1987).

In a content analysis of 11 major magazines in the first half of the twentieth century, LaFollette identified several major themes, especially a 'myth of scientific differentness' that stressed the 'extraordinary intelligence, foresight, [and] modesty' of scientists. 'Piercing eyesight' reflected the superb capabilities of insight attributed to scientists. LaFollette found the stereotypes of scientists divided into 'magician or wizard', 'expert' and 'creator/destroyer'. Nelkin used a more qualitative analysis when looking at newspaper coverage of science and technology in the last generation; she emphasised the number of 'pioneering', 'frontier' and military images to be found in writings about science. (Lewenstein 1995, pp. 354-5)

Lewenstein notes a number of other studies which examine images of science and scientists, few of which distinguish between characterisations in mass and specialist media.

**Psychological contexts**

There is some recognition of psychological factors in the metascientific literature. For example, Brannigan (1981, pp. 12ff) critiques four models of scientific discovery that he characterises as psychological: they are given respectively in the works of
Hanson, Blackwell, Kuhn and Koestler. Thus for Hanson, discovery is the psychological reassignation of the value of an object, fact or pattern, which is a type of learning: to ‘see in familiar objects what no one else has seen before’ (Brannigan 1981, p. 14). For Blackwell, discovery is also a type of learning but is a shift in gestalt, either as elaboration of existing structures or transformation of structures. Kuhn’s account deals with both the psychological activity of the individual and the social change of the scientific community: ‘According to Kuhn, discoveries occur when the conceptual suit of a paradigm no longer fits the body of knowledge, and unthreads in the form of anomalies’ (Brannigan 1981, p. 21). In Koestler’s account, discovery is the ‘synthesis of a single idea with two apparently inconsistent contexts’, a psychological process which accounts not only for scientific discoveries, but also artistic creations and comic inspirations (Brannigan 1981, p. 27). Brannigan’s critique of psychological accounts of discovery in favour of a sociological explanation is discussed in Appendix B.5.

In Callon’s four models for the dynamics of science (1995), three especially allow for psychological and other human contexts as factors in scientific development. Characterisations of science by competition highlight particularly the role of incentive and reward. Characterisations of science by sociocultural practice highlight social factors, but these include individual identification with group characteristics as well as psychological characteristics such as confidence. Characterisations of science by extended translation highlight the interactions and translations between all (human and non-human) actors or actants in a translation network, but allow for individual human factors as part of this network.

Elements of these psychological accounts describe mental activity are discussed in Appendix B.5 and summarised in the companion chapter on activity, but the notion of psychological context is broader than this. It also includes notions such as incentive, motivation and interest, which are inconsistent with the positivist legacy. An example of a theoretical treatment is the notion of human agency, as posited by Taylor and subjected to considerable discussion in Hiley, Bohman and Shusterman’s (1991) compilation of views on the so-called interpretive turn in philosophy:

For much of this century, positivist philosophy of science reinforced the distinction [between explanation and interpretation] through its view of the unity of science, which demanded a reduction of all sciences, including the social and behavioural sciences, to the ontology and methods of physics. The result was a clear demarcation of the scientific enterprise and interpretive disciplines. The distinction also implied a normative distinction that served to privilege the views about reason, knowledge, and the knowing subject inherent in the positivist view of science.

The recent impetus for rejecting the demarcation of the natural and human sciences has come initially from within the philosophy of the natural sciences, in challenges to positivism by the postempiricist philosophers of science such as Thomas Kuhn, Mary Hesse, and Paul Feyerabend. For positivism, the standard list of differences between the sciences and other forms of inquiry had derived from a view of the natural sciences that turned on the supposed neutrality of
observation, the 'givenness' of experience, the independence of empirical data from theoretical frameworks, the ideal of a univocal language, and belief in the rational progress of science. With the rejection of positivism and its thesis of the unity of science, many of the historic reasons for drawing a line between the natural and human sciences simply disappeared; distinctions between the disciplines were blurred by the suggestion of a much looser and interpretive conception of natural scientific inquiry. (Hiley, Bohman & Shusterman 1991, p. 3)

A distinction of this sort, between the natural sciences and the human sciences, is an example of boundary concerns, as we have discussed above in section 1.2. It is mentioned here, however, because it arises from the notion of human agency in science. The debate about this distinction is given in the sixteen contributions to Hiley, Bohman and Shusterman (eds) (1991) and, in essence, turns on the question of human agency in science. On the one hand is the view, given in Taylor, Kuhn and others, that the human and natural sciences are distinguished essentially by the question of human interpretation. For Taylor the human sciences are interpretive while the natural sciences are not; for Kuhn the natural sciences do have an interpretive basis, but are fundamentally concerned with problem solving (Kuhn 1991, pp. 22-3). On the other hand is the view, given by Rorty and others, that post-positivist views of science render such distinctions no longer useful, if they ever were. Rorty (1991 pp. 59-80) argues that all inquiry is recontextualisation, meaning the realignment and reformation of beliefs. While this view is contentious (and is debated by other contributors), the point here is Rorty does not oppose by rejecting the notion of human agency, but by arguing for universal human agency. Hence the debate is within the interpretive turn, not between interpretation and something else such as objectivity. This brings the range of contextual factors - social, organisational and others - to bear on natural science, but particularly as they apply to the interpretive individual.

**Human contexts in experimentation**

Collins and Pinch (1993) describe a number of episodes in science to show, among others things, this interpretive characteristic of actual rather than idealised science:

[Our book] presents a view of science as fallible and untidy, a matter of craft rather than logic. To do this it examines a series of experiments, some famous, such as the proofs of relativity theory, and some not so famous. In each case it shows that scientific certainties do not come from experimental method, but from the way ambiguous results were interpreted. (Collins & Pinch 1993, Frontispiece)

[W]e are going to display science, with as little reflection on scientific method as we can muster. We are simply going to describe episodes of science ... We are going to say what happened. Where we do reflect, as in the cold-fusion story, it will be reflections on matters human not methodological. The results will be surprising. The shock comes because the idea of science is so enmeshed in philosophical analyses, in myths, in theories, in hagiography, in smugness, in heroism, in superstition, in fear, and, most important, in perfect hindsight, that
what actually happens has never been told outside of a small circle. (Collins & Pinch 1993, p. 2)
Thus, for example, Collins and Pinch recount an early (1919) experimental test between Einstein’s and Newton’s predictions of the effect of gravity on light waves. While not widely understood even today, relativity theory was at that time not even widely understood among the physics community, and the opportunity for an experimental test under the supervision of so eminent a physicist as Eddington was significant. Briefly, Einstein’s and Newton’s theories gave different predictions of the minute bending of light rays such as might be measured as they passed near the large gravitational field surrounding our sun. A solar eclipse in 1919 gave an opportunity to measure this. The experiment required photographs to be taken of the sky during the eclipse (during the day), to be compared with photographs taken of the sky before and after the eclipse (but during the night, when the sky was dark). Two series of photographs were taken, one in Brazil (Sobral) and one off the West African coast (Principe). That the results ‘confirmed’ relativity theory, and so contributed significantly to the shift from Newtonian mechanics, has become part of science lore. However, Collins and Pinch show that the results were not logically compelling or decisive as the popular accounts imply, because (a) the difficulties in setting up such an experiment reduced the margin of confidence; (b) the photographic plates were not all clear; and (c) the final measurement data, on modern statistical analysis, could be interpreted in various ways depending on which plates were accepted or rejected:

In either case, it would be difficult to be able to provide a clear answer. Nevertheless, on 6 November 1919, the Astronomer Royal announced that the observations had confirmed Einstein’s theory ...

Do the results come down on Einstein’s side in an unambiguous way? The answer is that they do not. To make the observations come out to support Einstein, Eddington and the others took the Sobral 4-inch results as the main finding and used the two Principe plates as supporting evidence while ignoring the 18 plates taken by the Sobral astrographic. In the debate which followed the Astronomer Royal’s announcement, it appears that issues of authority were much to the fore. On 6 November 1919, Sir Joseph Thomson, the President of the Royal Society, chaired a meeting at which he remarked: ‘It is difficult for the audience to weight fully the meaning of the figures that have been put before us, but the Astronomer Royal and Professor Eddington have studied the material carefully, and they regard the evidence as decisively in favour of the larger value for the displacement’ ...

In 1923, however, an American commentator, W. Campbell, wrote:
Professor Eddington was inclined to assign considerable weight to the African determination, but, as the few images on his small number of astrographic plates were not so good as those on the astrographic plates secured in Brazil, and the results from the latter were given almost negligible weight, the logic of the situation does not seem entirely clear. (Quoted in Earman & Glymour, 1980, p. 78)
Eddington justified ignoring the Sobral astrographic results by claiming that they suffered from ‘systematic error’ ... It appears, however, that at the time he was unable to educe any convincing evidence to show that this was the case.
In the end, Eddington won the day by writing the standard works which described the expeditions and their meaning ... (Collins & Pinch 1993, pp. 50-1)

In concluding, Collins and Pinch acknowledge that this was not the only experimental work being done on relativity theory at that time, and that an overall case was forming that supported the theory. However, despite repetitions seeking to measure the bending of light by the sun, there was no decisive evidence of it until 1952, despite 1919 remaining the date accepted by the scientific community.

**Personality as a human context**

Other accounts of human context address factors such as the personality of the scientist. Two of the better known of such accounts is Watson's (1968) account of his and Crick's work on the structure of DNA, and Koestler's (1959) account particularly as it deals with the personal trials of Kepler. One is struck in the former by the role of personal ambition and in the latter (notably in the case of Kepler) by mood, and in both by the conviction that individual personality, interest and persistence were significant factors in the successes of these scientists.
1.8 Organisational contexts of science

Science is sometimes characterised by organisations of people and resources: it is practised in universities, research-oriented companies and government instrumentalities; scientists are organised into departments, faculties, disciplines or teams; and scientists interact using organisations like professional associations and scientific societies. The organisation of modern universities into faculties and departments of science, and of scientists in universities, government departments and private firms into research teams, is self-evident at a public level. Modern universities are organised typically into faculties or departments, some of which like Science, or of Chemistry, explicitly characterise science. Less well known, at least publicly, are roles of organisation identified through historical and other analyses. For example, the fundamental changes summarised in the notion of the Scientific Revolution are characterised partly by the formation of new organisations and societies and, subsequently, the reorganisation of existing organisations such as within the universities (Singer 1959; Oldroyd 1989; Ross 1990). Thus Ross (1990, p. 799ff) notes that the contemporary characterisation of science as being empirical and mathematical, and quite different from abstract and speculative philosophy, only began to emerge around the sixteenth and seventeenth centuries. The earlier indistinctness corresponded with the mediaeval organisation of the universities, which remained until the eighteenth and nineteenth centuries: a lower faculty of Arts or Philosophy (these being interchangeable terms) and the higher faculties of Theology, Medicine and Law. Arts subjects were held in lower esteem because they were mandatory prerequisites to study in the higher faculties but not available for higher study themselves, and the age of Arts students roughly corresponded with modern secondary school age. The indistinct science and philosophy were found, except in parts of medicine, in the curriculum of Arts/Philosophy, and were taught by people with no specialist expertise as we would recognise today. There was no concept of a professional scientist or philosopher.

Given this context, it is unsurprising that the new science emerged outside the university system. Its proponents either had non-academic professions or none, and as a consequence were unfettered by the existing disciplinary boundaries. They pursued their interests and aptitudes, and began to organise themselves accordingly:

However, the seeds of demarcation [of science] were already being sown. The seventeenth century saw the foundation of a number of societies and journals, a few of which were, from the start, effectively ‘scientific’ in the modern sense - in particular the Paris Academy of Science, and the Royal Society of London for Improving Natural Knowledge, and its associated journal. (Ross 1990, p. 803)

While descriptive histories of the scientific societies have been available for some time (the prestigious societies having their own historians from their inception), more recent
accounts have made more various critical analyses (Porter 1990, p. 36). Thus, the organisational context of science at this time delayed 'the institutionalisation of the emergent distinction between science, philosophy and other disciplines' (Ross 1990, p. 804). The existing organisation of the universities did not suit the rapidly changing field, as noted above, and when the universities did take up the new science, they did so within their existing organisation and scattered it throughout the Arts faculty.

The trend to more critical historical analyses arose from a concern to interpret and explain rather than merely to describe, which has had the effect of identifying a wider range of causes and effects than given in the earlier historical accounts:

Thus Morris Berman's history of the early years of the Royal Institution, to mention just one instance, was to dwell on the rapidity with which the initial idealistic aims of the Institution were abandoned under pressure from its financial backers. Such histories of formal scientific institutions have broadened out into studies of informal networks of practitioners ('invisible colleges'), into examinations of amateur as well as professional science and into analysis of wider 'audiences' for science. They have often drawn fruitfully upon the conceptual apparatus developed by sociologists of contemporary science, probing the 'social system of science' with its career structures, citation patterns, reward systems, intellectual property rights, publication networks and so forth. (Porter 1990, p. 37)

Thus organisation is given as a characteristic which affected scientific development and outcomes. Porter cites Ben-David's (1971) characterisation of the successive eminence of science in England, France and Germany as an account of organisation of science, although he is critical of its 'distracting teleology' (Porter 1990, p. 37). Ben-David's account is made partly in terms of different organisational contexts: the infant new science flourished initially in England with the support of a cadre of amateur enthusiasts or 'virtuosi', but later flourished in France which had established a state machinery of eminent professional scientists, and later still flourished in Germany where the reformed universities attracted eminent professors surrounded by teams of PhD students. Universities played a key role in the development of scientific ideas in nineteenth century Europe (Mason 1962, p. 549).

Porter also interprets Kuhn's (1962) characterisation of science by paradigms as a characterisation partly by organisation:

[Paradigms] were structures of thought (Gestalten). But they were also identified with an elaborate social scenario - the innovating scientist in his fief-like laboratory, flanked by a bodyguard of colleagues and students, pioneering a distinctive repertoire of techniques, experiments and (more widely), the endorsement of such paradigms through discipleship, text-books, patronage, and scientific education. (Porter 1990, pp. 37-8)

This is a clear characterisation of science by the organisation of physical, human, conceptual, strategic and other resources.

A final point about characterisations in terms of organisational context is that they are sometimes indistinct from those in terms of structure, arising from the sometimes
indistinct use of language in characterisations. This similarity is discussed in section 3 of Chapter 6, and organisations as structures are discussed more extensively in the Appendix B.4 and summarised in the companion chapter on structure.
1.9 Physical contexts of science

A popular characterisation of science, especially in the mass media, is by its physical context: it is practised in laboratories and field sites, and uses characteristic artefacts such as experimental apparatus. Laboratories, experimental apparatus and laboratory coats are strongly identified in the public mind as characteristics of science, because they are manifest and tangible artefacts. We have mentioned already the persona of the scientist as part of the human context, but part of the popular characterisation of the scientist involves the artefacts and paraphernalia surrounding the (usually male) stereotypic scientist. This notional scientist usually wears a white laboratory coat, but figures wearing other protective clothing and carrying other paraphernalia are commonly identified as scientists or technicians; schoolchildren, for example, often put pens in the top pocket of scientists they are asked to draw. The mass media and other forums exploit these images when characterising science: any number of movies, television shows, animated cartoons and print media caricatures resort to these stereotypes to characterise science or scientists succinctly. Thus the physical contexts of science - the physical or tangible artefacts and locations - largely shape public characterisation of science. In the sense that these tangible artefacts and locations are self-evident they are taken here as relatively unproblematic and needing no further elaboration.

The role of artefacts and locations

Of greater metascientific significance is the interpretation of the role of artefacts and locations in science. Thus a stronger argument for physical context is that it partly constitutes, or is integral to, science. This view is part of the post-positivist climate of metascience, and includes scientific apparatus:

Scientific apparatus may likewise be seen as creating a man-made [sic] (i.e., social) milieu for science. Shapin and Schaffer have recently argued, for example, that the development of pneumatology in the seventeenth century hinged upon the invention - and not least the highly-prized actual physical possession - of specific pieces of apparatus, above all, the air pump, as a means of generating experiences unknown in the regular course of Nature and of creating intellectual authority. (Porter 1990, p. 38)

That is, scientific apparatus helps create the conditions in which scientific claims are made, tested, falsified or confirmed. Porter argues that the work of Guericke, Boyle and Hook, protagonists of the early work with the air pump, had to 'win control of the grounds of belief', since some results contradicted the accepted authorities of knowledge and common sense. Such a contradiction is less striking in the twentieth century, he says, when scientific knowledge is the accepted (albeit criticised) authority; that is, there is an acceptance that scientific knowledge is not always commonsensical. Wolpert (1992) pursues this argument, claiming that science 'does not make common sense', firstly
because it is often counter-intuitive and secondly because it requires awareness of the pitfalls of common sense thinking (*The Unnatural Nature of Science*, 1992). In the early work with the air pump, the physical apparatus played a role in demonstrating the validity of some counter-intuitive and counter-authoritative beliefs, although together with other strategies such as reasoning and argument.

More striking examples of this are probably the major theoretical developments in twentieth century physics - the quantum and relativity theories. In the increasingly ‘high-tech’ areas that characterise much contemporary science, the making and testing of scientific claims without the apparatus is inconceivable. This has much to do with the increasing interdependence between science and technology, as discussed earlier. We have mentioned Redner’s (1987) detailed account, in which Classical science is characterised by scientific apparatus that were used as craft tools to test theories devised independently of the tool, whereas in World science the relationship between theory and instrument is reversed:

... for utilising these tools in a science restructures the whole process of research and alters the very meaning of data and knowledge ... [T]he instrument itself is being explored and theories devised and objects found to satisfy the results of that exploration. Thus in such a science technification assumes prominence over all the other factors of science. In many other sciences technification is almost of equal importance in that the phenomena being studied would not exist or at least would not be available for purposes of investigation without highly technified means. This is particularly the case in sciences dealing with extreme conditions not usually encountered in terrestrial nature ... (Redner 1987, p. 65)

This argument for the role of apparatus in technified science is perhaps less obvious than for the use of tools in classical science. The comment, above, that scientific apparatus help create the conditions in which scientific claims are made, still holds, but Redner extends this role of apparatus in technified science. Thus he characterises chaos theory, for example, as entirely a product of using computers, and inconceivable without them. Redner claims that the role of computers, in this example, is not fundamentally to measure or interact with an external reality, but to generate data which itself becomes the subject of study. The same applies to many areas of contemporary science which are pursuing extremes of temperature, pressure, electric and magnetic fields, energies, and intervals of time; the example of the cyclotron, as given earlier, is a specific instance. These sciences develop only to the extent of technological development. Marcuse (1970) has also argued an integral role for technology in science, that science, through its world view (which the present thesis interprets as part of the belief system) and it application in technology, helps determine the nature of the industrial society. In his view, the positivistic scientific world view in which Nature is controllable - a ‘technological universe’ - legitimises or reifies a functional role for both people and Nature in serving technological/capitalist organisations (Marcuse 1970, pp. 136-7).
Laboratories as the contextual focus

Another strand of vigorous interest in STS is laboratory studies, in which focus of attention is on laboratories rather than either experiments or the sociology of organisations (Knorr Cetina 1995, pp. 140ff). Laboratory studies are not limited to a notion of the physical laboratory, but rather take the context of the laboratory and everything in it as the basis for analysis: the physical context is the setting for a range of activities and resources in which knowledge is constructed. The genre of laboratory studies began by noting that the experiment traditionally underpinned the epistemological claims of science. They found, however, that the experiment was typically characterised by its methodology - testing theories, experimental design, control group, factor isolation, blind and double blind procedure, and replication - which has had the effect of leaving unexamined what actually happens (real time processes).

This is a different approach to both methodological characterisations of experiment, which concerned only technical content, and organisational characterisations, which concern the influence of organisational structure and activity on scientific outcomes. By shifting the focus to the laboratory, laboratory studies were able to 'consider the technical activities of science within the wider context of equipment and symbolic practices within which they are embedded', without ignoring the 'technical content' of scientific activity (Knorr Cetina 1995, p. 143). This is intended to characterise all activities that produce scientific knowledge: technical, symbolic and political. Although grouped under a single label, laboratory studies provide a range of characterisations of science; they do not posit a single, agreed model. However, there are some common themes that illustrate the use of physical context in characterising science.

Primarily, laboratory studies construe laboratories as significant in scientific development and therefore theoretically important in understanding science. The success of science arises in part from laboratory activities that are more than just the methodological, or concerning rationality or validation. Based on work by Merleau-Ponty (1945, cited by Knorr Cetina 1995, p. 144ff), the response in laboratory studies has been to investigate how laboratories serve to 'reconfigure' the 'system of self-others-things':

The system of 'self-others-things' for Merleau-Ponty is not the objective world independent of human actors or the inner world of subjective impressions but the world-experienced-by or the world-related-to agents. What laboratory studies suggest is that the laboratory is a means of changing the world-related-to-agents in ways that allow scientists to capitalise on their human constraints and sociocultural restrictions. The laboratory is an 'enhanced' environment that 'improves upon' the natural order as experienced in everyday life in relation to the social order. (Knorr Cetina 1995, p. 145)
The environment in the laboratory can be 'enhanced' for scientific study in several ways: by substituting versions of the objects under study, such as growing cell cultures rather than entire plants; by spatially relocating the objects into the laboratory, so they can be studied independently of their distribution; and by temporally relocating the objects, so they can be studied independently of natural cycles. Thus laboratories allow certain properties to be selected for study in the local conditions and social order. This means that there are both epistemic and social effects:

The power of the laboratory (but also of course its restrictions) resides precisely in its exclusion of nature as it is independent of laboratories and in its 'enculturation' of natural objects. The laboratory subjects natural conditions to a 'social overhaul' and derives epistemic effects from the new situation. (Knorr Cetina 1995, p. 146; emphasis in original)

One approach of laboratory studies has been to characterise the system of self-others-things as a network of actors or 'actants', as in Latour (1987). In these accounts all entities - human and non-human - that have the ability to 'act' are characterised as actants, which could be a researcher carrying technical activity, another person who 'creates statements and constructs artefacts', a technical artefact that produces activity as part of the study, or a statement which attributes a property of action (Callon 1995, pp. 53-4).

Each of the actants contributes meaning, and is considered connected to the other actants by a network of interactions. For example, humans might contribute meaning by theorising, or by acting in one way rather than another; a piece of apparatus contributes meaning by the particular way it responds or works, rather than by responding in some other way. The network develops by the action of actants on other actants, and so translates their meaning:

The power of actors (such as a captain of industry, or the Rijkswaterstaat, or a Mafia leader) does not consist of something inherently special in those individuals or institutions but originates from the networks they control. A characteristic of the actor-network approach ... is its ontological basis. By not accepting a fundamental distinction between human and non-human actors, which is central to western sociology and indeed to most post-Kantian thinking, the actor-network approach is based on a pre-modern footing ... A 'principle of generalised symmetry' is adhered to: Analyse the human and non-human world with the same conceptual framework; in other words, the explanation of the development of sociotechnical ensembles involves neither technical nor social reductionism ... (The actor-network approach draws on semiotics. By using the term actant, the traditional social science connotations of the word actor are avoided). (Bijker 1995, p. 251)

By characterising all participants or actants equally, the contribution of each actant to the overall meaning is better understood, and avoids biasing the explanation in terms of social factors such as politics, finance or fear, or on technical factors such as increased knowledge or better equipment. Actor-network characterisations clearly appeal to more
than just the physical context, but they are mentioned here because they propose a fundamental re-characterisation of the physical context as a means of better understanding scientific progress.
## Table B.1.1

**Examples of key metascientific characterisations by context**

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<th>Author</th>
<th>Viewpoint</th>
<th>Reference to context, as in contribution to knowledge</th>
<th>Identified in the work of ...</th>
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<tbody>
<tr>
<td>Suppe 1973, 1979</td>
<td>Received View</td>
<td>normative abstract historical-intellectual context only, as in the reduction of earlier theories into more inclusive ones, or the expansion of scope of theories; no cultural or psychological context</td>
<td>Carnap</td>
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<tr>
<td></td>
<td>sceptical</td>
<td>various but limited reference; actual rather than ideal descriptions of mainly abstract intellectual context</td>
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<td></td>
<td>descriptive</td>
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<tr>
<td>Weltanschauungen (world view)</td>
<td>various; science as human activity within conceptual and cultural perspective</td>
<td>Bohm, Feyerabend, Hanson, Kuhn, Popper, Toulmin</td>
<td></td>
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<tr>
<td>semantic or model-theory</td>
<td>various; description of abstracted phenomena within specified scope</td>
<td>Beth, Suppe, Suppes, van Fraassen</td>
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<tr>
<td>historical realism</td>
<td>actual practices, in historical and contemporary contexts</td>
<td>Lakatos, Shapere, Toulmin</td>
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<tr>
<td>Bhaskar 1983</td>
<td>empiricism</td>
<td>no reference to ontological, psychological or social contexts</td>
<td>Francis Bacon, Berkeley, Hobbes, Hume, Locke, Mach (positivism), Mill, Russell, Vienna Circle (logical empiricism)</td>
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<td></td>
<td>idealism</td>
<td>psychological context (mental constructs or ideas)</td>
<td>Berkeley, Fichte, Hegel, Hume, Kant, Plato, Schelling,</td>
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<td></td>
<td>realism</td>
<td>intellectual context, perhaps psychological context (Platonic, Aristotelian, and perceptual or empirical realism) intellectual, ontological and social contexts (scientific realism)</td>
<td>Aristode, Bachelard, Bhaskar, Duhem, Feyerabend, Hanson, Harré, Hesse, Hume, Kant, Koyré, Kuhn, Plato, Popper, Putnam, Quine</td>
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<tr>
<td>Nussbaum 1989</td>
<td>rationalism</td>
<td>psychological, as in mental constructs</td>
<td>Descartes, Kant, Plato</td>
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<td></td>
<td>empiricism/positivism</td>
<td>acontextual (implicit intellectual context)</td>
<td>Bacon, Comte, Hempel, Hume, Locke</td>
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<td></td>
<td>constructivism</td>
<td>(a) inner disciplinary criteria (rational, logical, empirical) (b) outer-disciplinary factors/values (social-psychological, historical)</td>
<td>(a) Popper, Lakatos, partly Kuhn (b) Kuhn, Toulmin, partly Lakatos</td>
</tr>
<tr>
<td>Boyd, Gasper and Trout 1991</td>
<td>post-positivist consensus comprising (a) post-positivist empiricism, (b) neo-Kantian constructivism, and (c) scientific realism</td>
<td>Scientific methods and knowledge are not acontextual, but are theory-dependent.</td>
<td>(a) Partly Popper (b) Hanson, Kuhn (c) Boyd, Goodman, Kripke, Putnam, Quine</td>
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<td>Pickering 1992</td>
<td>empiricism</td>
<td>objective (that is, intellectual context only)</td>
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<td>relative to culture</td>
<td>Kuhn, Feyerabend</td>
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<td>sociology of scientific knowledge (SSK)</td>
<td>relative to interests</td>
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<td>Callon 1995</td>
<td>science as rational knowledge</td>
<td>Hesse, Holton, Popper</td>
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<td></td>
<td>intellectual context of researchers as utterers of statements; science as part of an open society</td>
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<td>science as competitive enterprise</td>
<td>Althusser, Ben-Cole, David, Freudenthal, Hull, Merton, Popper</td>
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<td>intellectual context of researchers as members of disciplines with internal orders and functional internal/external boundaries</td>
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<td></td>
<td>science as sociocultural practice</td>
<td>Bachelard, Barnes, Collins, Fleck, Knorr, Kuhn, Mulkay, Pinch, Ravetz, Rudwick, Schaffer, Wise, Wittgenstein</td>
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<td></td>
<td>socio-cultural and epistemic contexts; statements only have meaning within a context; researchers within constraints, demands and interests; networks of relations; rules; boundaries between science and its environments constructed by the actors</td>
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<td>science as extended translation</td>
<td>Amaan, Callon, Foucault, Knorr Cetina, Latour, Pickering, Wise, Woolgar</td>
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<td>activities and interactions of all participants ('actants')</td>
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### Table B.1.2

A comparison of the conceptual organisation of four general texts in the history and philosophy of science

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<td></td>
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<td>Philosophy of science is concerned with explicating science, through</td>
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<td></td>
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<td>A. Metaphysics</td>
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<td>B. Logic</td>
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<td>C. Epistemology</td>
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<td></td>
<td>A. Metaphysics as categories:</td>
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<td>a. Materials</td>
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<td>b. Individuals</td>
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<td>c. Qualities</td>
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<td>d. Relation</td>
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<td></td>
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<td>space</td>
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<td></td>
<td>2. The Great Adventure</td>
<td>2. Part 1: Rational Cosmologies</td>
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<td></td>
<td>The foundations: to c.400 BC.</td>
<td>1. World created by God:</td>
<td></td>
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<td></td>
<td>Unitary systems of Thought: Athens, 400-300 BC.</td>
<td>Pythagoras</td>
<td>2. World seeking itself:</td>
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<td>Philolaus</td>
<td>Ptolemy</td>
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<td>Heraclides</td>
<td>Saint Augustine</td>
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<td>Plato</td>
<td>Aquinas</td>
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<td>Aristotle</td>
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<td>Aristarchus</td>
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<tr>
<td>4. The Failure of</td>
<td>5. The Failure of Knowledge The Middle Ages: Theology, Queen of the Sciences, c. AD. 400-c. 1400)</td>
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<td>Inspiration</td>
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<tr>
<td>Renaissance view of Nature</td>
<td>6. Revival of Learning: Rise of Humanism; Attempted Return to Antiquity (1250-1600)</td>
<td></td>
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</tbody>
</table>
### Appendix B.1: Context

#### 7. The Insurgent Century
- Downfall of Aristotle (1600-1700): New Attempts at Synthesis

#### 4. World subject to laws: Kepler
- 5. A world system: Galileo’s single hypothesis
- 6. An a priori world: Descartes

#### 2. Corpuscularian
- (i) Ultimately there is only one substance, and change is possible because it is divided into units, which are capable of motion and hence rearrangement. 
- (ii) The arrangements of the corpuscles is the real essence of bodies, and defines their primary qualities. 
- (iii) Geometry as the science of shape, and mechanics as the science of motion are the fundamental sciences. 
- (iv) Changes in our ideas of secondary qualities are the result of changes in the arrangement and state of motion of constituent corpuscles. 
- (v) Basically the only real happenings were redistributions of motion brought about through action by contact. 
- (vi) The ultimate properties of corpuscles were their power to fill space (their extension), and their power to resist instantaneous increments of motion (their inertia). 

#### 8. The Mechanical World
- Enthronement of Determinism, 1700-1850
- 9. Culmination of the Mechanical View of the World, c. 1850-c. 1900

#### 7. A world subject to one law: Newton

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#### The modern view of Nature
- Consequences of this view:
  - Change progressive, not cyclical
  - Nature no longer mechanical
  - Teleology reintroduced
  - Substance resolved into function
  - Minimum space and minimum time

#### Part 2: Relativistic cosmologies: Einstein

#### 3. Powers
- The corpuscularian inheritance:
  - principle of structural explanation
  - qualitative to quantitative
  - differentiation of instruments
## B. Logic

Forms of reasoning in science:
- Logic as rules of correct reasoning
- Inductivism
- Falsifiability
- Positivism

## C. Scientific Knowledge

Epistemological theories:
- Phenomenalism
- Fictionalism
- Scepticism
- Realism
Appendix B.2

Argument from the metascientific literature emphasising the dimension belief system

Debates in the metascientific literature characterise science variously by belief system, which again supports a broad interpretation of science. Appendix B.2 indicates aspects of belief system as it used in characterising science:

B.2.1 The notion of a belief system
B.2.2 Some current metascientific positions
B.2.3 The role of belief system in characterising a western European scientific tradition
B.2.4 Causality
B.2.5 Attitudes to Nature
B.2.6 Nature and magic
B.2.7 Nature and God
B.2.8 Nature and mathematics
B.2.9 Metaphysical beliefs
B.2.10 Experimentation
B.2.11 Models and metaphors
B.2.12 Other belief systems

This list addresses some recurring themes, and is not definitive; it is intended as an indication of scope.
2.1 Beliefs as a system

The literature contains a variety of arguments that there is a collective and interrelated set of meanings for terms such as belief, attitude, value and criteria for judgements. John Heil, for example, has argued that belief has a central place in epistemology, a long tradition in western philosophy, where it forms an enduring account, or standard picture:

The ground-level epistemological concepts of truth, falsity and justification apply primarily to beliefs, and only derivatively, if at all, to knowledge. Belief is thus central to epistemology.

Plato, in the *Meno*, set the tone for subsequent discussion. There, and in the *Theaetetus*, he distinguishes knowledge, belief, opinion and judgment, and advances a conception of these states of mind according to which they incorporate a pair of components, one intentional or representational, one causal. In F. P. Ramsey’s phrase, a belief is viewed as a ‘map of neighbouring space by which we steer’ (Ramsey, 1978, p. 134).

This dual-component picture of belief constitutes what has become the standard picture. It was embellished, for instance, by Hume, who regarded beliefs as ‘ideas’ supplemented by a particular ‘sentiment or feeling’ in virtue of which those ideas come to serve as guides to behaviour. This conception, like Descartes’, depicts beliefs as conscious episodes. Although we are often conscious of our beliefs, however, our being conscious of them seems inessential to their psychological role.

The standard picture is nowadays reflected in the notion that beliefs are to be located among the propositional attitudes, states of mind comprising (1) propositional contents paired with (2) attitudes toward those contents. In addition to beliefs, these include desires, wishes, intentions, fears, doubts and hopes. The objects of beliefs, then, are taken to be propositions. (Heil 1992, p. 45)

This relationship between propositions of knowledge and belief, widely accepted in HPS and other fields, is discussed in Appendix B.6 and the companion chapter on knowledge. Here, Heil observes that other concepts such as truth, falsity and justification, that commonly characterise science, also entail or represent beliefs. Beliefs are also characterised by attitudes or dispositions (sentiment or feeling) which, in some interrelated sense, guide our behaviours and judgments. Heil (1992, pp. 45-8) notes that this standard picture of belief has been remarkably resilient, but also notes some criticisms of it and alternatives to it; we will mention some of these both in this chapter and in Appendix B.6.

For the present it will be more helpful to consider how the literature accounts for the nature and interrelatedness of beliefs, attitudes, values, criteria and so on. The most plausible and useful approach is to consider that these concepts are related because they are elements of a system of beliefs. It will therefore help to consider a theory of belief systems.

The notion of a belief system

Given the often unstated and unrecognised character of beliefs, attitudes and so forth, it will help to examine the notion of belief system as an organising concept for these sets of cognitive states. Rokeach (1972) has argued that beliefs, attitudes and values are interrelated and affect behaviour:
Beliefs, attitudes and values are all organised together to form a functionally integrated cognitive system, so that a change in any part of the system will affect other parts, and will culminate in behavioural change. (Rokeach 1972, p. ix)

Rokeach traced historical attempts to clarify and distinguish terms such as attitude, value, belief, sentiment, ideology, and so forth, and proposes that it is meaningful to speak of them together as a belief system:

A belief system represents the total universe of a person’s beliefs about the physical world, the social world, and the self. It is conceived as being organised in several dimensions, and additional dimensions can be added as required by further analysis or empirical research. A belief system can further be analysed in terms of subsystems of varying breadth or narrowness. (Rokeach 1972, p. 123)

Thus for Rokeach (pp. 123ff), a belief system can be considered as comprising subsystems such as attitudes, ideologies and values. Various kinds of beliefs include faith, delusions, and stereotypes; sentiment he judges to be an older term usually synonymous with attitude. However, this is a general model that tends to emphasise psychological aspects of belief systems.

A model better suited to the present thesis is that of Borhek and Curtis (1975), which explicitly discusses scientific belief systems as one among many possible belief systems, and which has scope and detail suited to breadth of the present analysis. We will examine this theory in some detail.

A theory of belief system

Borhek and Curtis (1975) have argued that beliefs have a partly social character, and that they can be better understood using a theoretical framework of belief systems that accounts for beliefs, values and attitudes. They argue that systems of beliefs are found universally in culture; science is, or entails, one such belief system. Their theory is a general account that can accommodate a variety of metascientific viewpoints. It provides a coherent account of the sometimes implicit mix of beliefs, attitudes and values found in the summary statements; it is plausible and relevant to the concerns of the present thesis.

Borhek and Curtis characterise belief systems by defining properties and elements. Following their interest in the sociology of belief, Borhek and Curtis argue that belief systems are explained by more than the psychology of individual believers. The defining properties follow from this assertion. Thus people are personally committed to belief systems. At the same time, belief systems exist independently of those individuals who are committed to them: thus belief systems can exist longer than the life spans of individual believers. Belief systems also vary in substantive content and in the definition of their boundaries, examples including science and orientations within science, orientations within the study of history, religious groups, political groups, and so on. We will return to some of these defining properties of belief systems in later discussion, but it is the proposed
elements of belief systems that will best inform this stage of the argument for beliefs in science.

Elements of a belief system
The elements of a belief system include the beliefs, attitudes, values and criteria for judgements, together with other statements that could comprise a belief system:

Many of these elements are implicit understandings within most belief systems. Indeed, many belief systems are formally incomplete in that no real stance is taken, implicitly or explicitly, on some issues ...

Our emphasis on systems of belief is not meant to represent an analytic framework imposed by the investigator, but rather to represent an important characteristic of the way people use beliefs. The necessity for considering system is clear from the fact that out-of-context beliefs are meaningless. More importantly, when people use one or more beliefs, they adduce the system (whether it exists or not) to a variable degree. (Borhek & Curtis 1975, p. 8)

Borhek and Curtis propose seven possible elements, although one or more may be absent in particular cases. The order, which is reproduced here, reflects the logical order required to understand a belief system, although this order appears to be the reverse order of the development of elements in practice.

(i) The first element of belief systems in this model is values, which interact with behaviour:

Implicitly or explicitly, belief systems define what is good or valuable. We refer to 'ultimate' values or goals here in the sense that they are the values in terms of which proximate goals are justified. Although we shall speak of goals and values as guiding behaviour, 'justifying' or 'legitimising' would usually be more appropriate. Values tend to be abstract summaries of the behavioural attributes which society rewards, formulated after the fact. Groups tend to think of themselves, however, as setting out to do various things in order to implement their values. That is, values are perceived as a priori, when they are in fact a posteriori to action. (Borhek & Curtis 1975, p. 9)

This difference between the perceived and actual role of values, while it may be perplexing to the observer, reveals the role of values in the functioning of the group of believers. Courses of action are legitimised by these values, and the commitment of individuals to collectively agreed values 'allows almost automatic concerted collective action' (p. 9). New courses of action can then be based on principles derived from earlier experience and agreed upon. The relationship between the abstract nature of beliefs and the concrete nature of actions based upon them can lead to other consequences that may be also unclear to the observer at first:

The substitution of concrete and observable social behaviour for abstract and unmeasurable values frequently results in these values acquiring implications they did not initially have. For example, science may be taken as valuing expanded understanding; at the abstract level this may not imply the value of greater government expenditures on the space program, but at the concrete level it might entail exactly that. (Borhek and Curtis 1975, p. 10)
There is also the implication, argued in this chapter, that just as some core values entail attendant values, some beliefs that are fundamental will entail attendant beliefs.

(ii) The second element in belief systems is the **criteria of validity**: the criteria by which statements made within the belief system are validated. These can and do change within belief systems, although their level of abstractness and stability are measures of difference between belief systems. The clear definition of mathematics as a belief system, for example, relies upon the clarity of the main criterion for validity - consistency. Other belief systems have to rely on more concrete criteria:

At the abstract level, the intuition of science uses logic and empirical truth with the implicit assumption that they ought to be compatible in the long run. Concretely, adjustments between the logic we understand and the events we can observe have to be made. A rigid, perfectionist insistence that all our methods be perfect before we speak would lead to silence and the death of science. In practice we allow a little of what pool players call 'slop'. Moreover, there are other criteria in actual scientific thought such as parsimony, elegance, and practicality. (Borhek & Curtis 1975, p. 10)

Criteria of validity apply in this case to decisions about activity, as do other elements of belief systems. A criterion historically applied to science is simplicity, often known as Ockham’s (or Occam’s) razor.

(iii) The third element is **logic**, which can also be taken to include **language**. This is the set of rules by which substantive beliefs within the belief system are related to each other, and will differ between belief systems such as algebra, ethics, physical science and musical harmony, for example. The rules in systems such as science and law are ‘worked out and very explicit’ (p. 11) and, once known, can be applied in new actions within the belief system. This is often proposed as part of the rationale for processes as characteristics of science (see Millar & Driver 1987); such a rationale is discussed in the companion chapter on activity. Scientific language is discussed in the companion chapter on structure and Appendix B.4.

(iv) The fourth element is the **perspective**, or cognitive map. This comprises statements about the individual believers, the group itself, the environment external to the group of believers, and the and the relationships between and relative standing of all three:

Central in most perspectives is some statement of where the belief system and/or the group that carries it stands in relation to other things, especially in relation to other groups and world views ... The perspective may be stated as a mythology. It explains not only who we are and how we came to be in cognitive terms, but also why we exist in terms of the values. Meaning and identification are provided along with cognitive orientation. (Borhek & Curtis 1975, pp. 11-12)

The perspective may comprise a set of conceptual tools or a classification system, which in themselves select particular features of the external environment for attention. In the example of a cricketer, different belief systems could call to attention the batting average, the personality, the state of grace and the trajectory of the ball. The present thesis argues
that different belief systems could draw attention to different characteristics, such as knowledge or the institutional structure. Thus physicists, ecologists and mining geologists, for example, and philosophers, historians and sociologists of science, no doubt differ in their scientific perspectives.

(v) The fifth element is the **substantive beliefs**. Substantive beliefs are the actual content of the belief system, and can only be understood in terms of the first four elements: values, criteria of validity, logic, and perspective. Scientific laws represent substantive scientific beliefs, as discussed in the companion chapters on knowledge and structure and Appendix B. (An implication of Borhek and Curtis’ theory is that the other dimensions proposed in the present thesis also include substantive beliefs; this is argued shortly.)

Substantive beliefs are by their nature more explicit in the thinking of believers than the first four elements:

> Historically, of course, the previous four elements may have been built up around a substantive belief to give it meaning and justification. The individual believer is usually better able to verbalise substantive beliefs than he [sic] is values, criteria, logical principles, or orientation, which are apt to be the unquestioned bases from which he proceeds. (Borhek & Curtis 1975, p. 12)

That is, the conscious concern of the believer is usually the substantive beliefs; however, they are based on values, criteria, logical principles and orientation or perspective. These bases for the substantive beliefs are usually the concern of the philosopher or meta-analyst, who is often trying to clarify inexplicit assumptions. Thus the believer may have substantive beliefs without there being a framework of assumptions to support these beliefs, and Borhek and Curtis observe that this has been the case with, for example, religious systems:

> It seems clear that such systems evolve highly detailed and highly systematic theologies long after they come into existence and that they came into existence as a bundle of rather specific substantive beliefs. The believers interact, share specific consensuses, and give themselves a name. Then professionals work out an orientation, logic, sets of criteria of validity, and so forth. (Borhek & Curtis 1975, pp. 12-13)

While not claiming that science is a religion, this seems a reasonable analysis of the relative standing of science and metascience. The variety of metascientific views presented in the present thesis indicates that, while scientists continue to ‘do science’, various theories of science continue to be argued as we try to understand science better. Some of these accounts, while lacking unanimous support, are sufficiently plausible to have been used to inform scientific practice. In any event, the values, criteria, logical principles and perspective, tending to be the ‘unquestioned bases’ for scientific activity are the very elements identified within the summary statements on which this chapter is based.

(vi) The sixth element of belief systems is **prescriptions and proscriptions**, which refer to observable behaviour and include norms for behaviour and recommendations for policy or action. Paul Feyerabend’s *Against Method* (1975) is in part an example of both
the 'statement-of-what-is wrong' and the visionary polemic that fulfils this role. Prescriptions and proscriptions more closely describe actual behaviour than do substantive beliefs, and are therefore more subject to pressures for change from the real world. It is reasonable to infer that they are more subject to external, or social, cultural or institutional pressures than are substantive beliefs and the other elements that underpin them.

(vii) Seventh and last of the proposed elements of belief systems in this model are 'associated beliefs concerning means to attain valued goals', summarised as technology:

Some such beliefs concern the legitimacy or appropriateness of means, while others concern only the effectiveness of various means. Technological beliefs are not used to justify or validate other elements of a belief system, although the existence of technologies may limit alternatives among substantive beliefs. (Borhek & Curtis 1975, p. 13)

The reference here to legitimacy or appropriateness of means implies some belief concerning criteria of validity, although this is not clear. Technological beliefs, in the sense here of being elements of a belief system, concern means rather than ends, and include the physical activities normally associated with groups, as well as organisational strategies and tactical procedures. Technological beliefs represent a much more pragmatic level of beliefs, concerned as they are with doing:

(T)echnology is often the meeting ground for fundamentally different belief systems, often to the dismay of purists. There is a kind of pragmatic marketplace of beliefs, with the remarkable feature that specialists tend to be excluded by their expertise and the purity of their thought. (Borhek & Curtis 1975, p. 14)

Thus technicians, requiring less commitment to the detail of the belief system, are more pragmatic, less idealistic. Changes in practice, meaning changes in the technological beliefs of a belief system, can cause changes in the other elements even though these other elements are logically prior. Thus there have been scientists regarded as great experimenters, but who may have written little analysis of their experimental success: they have contributed much to science but formally little to metascientific theory.

This is but one of many possible models of a belief system, but it serves to show that this concept integrates a number of elements like beliefs, assumptions, values, attitudes, criteria for judgements, and world views, that are identified, in the summary statements of science. As the present chapter will show, these elements are identified more broadly in the metascientific literature, and constitute an integral part of multidimensional characterisations of science.
2.2 Current metascientific views of belief systems, or elements of belief systems

There are various accounts of belief system in the metascientific literature. Table B.2.1 presents an overview of various analyses of metascientific viewpoints, to enable some comparisons based on notions of knowledge. Each view addresses at least one aspect of belief system.

In contemporary HPS, the present thesis recognises three main positions: post-positivist empiricism, idealism or neo-Kantianism, and scientific realism. In (a) **empiricism** we gain our knowledge from experience, that is, from sense data; in strong empiricism, such as positivism, certain knowledge arises only from our perceptions. In (b) **idealism** or **constructivism** our knowledge is structured by the intellect, as in the theory-laden-ness of observations or the selection and interpretation of observations through a world view or **Weltanschauungen**:

The constructivist asks, ‘What must the world be like in order that a methodology so theory-dependent as ours could constitute a way of finding out what’s true?’ She [sic] answers: ‘The world would have to be largely defined or constituted by the theoretical tradition which defines that methodology’. (Boyd 1983, p. 207)

In strong idealism or constructivism, we can only know what the mind is capable of construing or constructing. In (c) **scientific realism** the possibilities of our knowledge are given in, or constrained by, an external reality, but our knowledge of it is produced socially and psychologically:

[T]he world might be one in which the laws and theories embodied in our actual theoretical tradition are approximately true. In that case, the methodology of science might progress dialectically. Our methodology, based on approximately true theories, would be a reliable guide to the discovery of new results and the improvement of older theories. The resulting improvement in our knowledge of the world would result in a still more reliable methodology leading to still more accurate theories, and so on. (Boyd 1983, p. 207)

As with the meta-analyses in the companion chapters, different HPS perspectives such as empiricism, idealism and realism, are interpreted variously by different authors; see Table B.2.1.

This is also the case in contemporary STS, as given in Callon’s (1995) overview of approaches in the field. Thus, where science is characterised as (a) **rational knowledge**, knowledge is given in scientific statements that may have different assumptions in different accounts:

Nature’s reality is asserted and the statements produced are seen as an increasing theoretical approximation or a better experimental description. Or, alternatively, one may not express any opinion about this reality and simply concentrate on the endless production of more and more robust or reliable statements. Whether the

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1 These views largely represent differences in beliefs about being (ontology) and knowledge (epistemology).
statements that are produced tend toward the truth, relate together ever-increasing numbers of empirical observations, or increase our ability to control and manipulate the world, the tragic beauty of Model 1 is that it is scientists and scientists alone who have to choose which statements to preserve and which to discard. (Callon 1995, p. 36)

Where Callon refers to the tragic beauty, presumably he means that the idealistic characterisations given in normative accounts, such as positivism, saw science as the only guarantee of true and objective knowledge, and therefore scientists as the only people qualified to make judgments about truth and objectivity. Some see a beauty in the order of Nature, and this view of science would argue that only science can give us true knowledge of that beauty. The tragedy, presumably, is that only scientists can appreciate the true beauty. This view of science is contested: various alternative characterisations argue that there can be no absolute objectivity and that in many, if not all, instances, claims to scientific knowledge are not made only by scientists. The tragic beauty arises because of the shift from normative accounts in metascience - one science should be - to descriptive accounts - what actually happens.

Where science is characterised as (b) a competitive enterprise, it simply assumes the content of the knowledge to be published and judged by colleagues. However, it places great importance on the preservation of scientific rationality from external influences in society:

Science produces knowledge, but the institution that supports it has an essential function, that of enabling rational knowledge to develop. When the dynamics of science are hindered, reason is affected. (Callon 1995, pp. 41-2)

Where science is characterised as (c) sociocultural practice, it assumes that ‘science must be considered to be a practice whose cultural and social components are as important as the constraints that arise from the order of discourse’ (Callon 1995, p. 42). This model argues that to extract scientific statements from their context of production and negotiation is to ‘strip them of their meaning’ (p. 43). This is because science ‘is involved in social relations that have their own logic’ (p. 49). Thus, for example, Barnes has argued that scientific knowledge has always been in response to particular interests, but that this is insufficient to account for knowledge:

Scientific knowledge can be seen always as a response to one kind of interest, that of prediction and control, but its contents are organised and structured according to different and changing social configurations. (Callon 1995, p. 49)

That is, the history of science shows that science responds to problems that are historically contingent; this can be interpreted both narrowly, in the sense of predicting and controlling phenomena by the activities of scientists, and in the broader sense that wider social groups such as industry and governments affect outcomes by supporting or proscribing particular activities and purposes. The present thesis interprets Barnes as characterising science here by knowledge, purpose (interest), context (historical and social factors) and belief system
Appendix B.2: Belief system

(the criteria and assumptions that these other dimensions embody). Another example is the work of Collins and others on the replication of experiments:

No replication has ever resembled the experiment that inspired it, even when the instruments have been perfectly calibrated and procedures highly standardised. Transfer involves loss and creation, elimination and addition. (Callon 1995, p. 49)

Where science is characterised as (d) extended translation, it concerns the production of statements, as in model (a), but rejects the assumptions of that model:

The notion of translation network suggests that it is not only the distinction between nature and society that is outdated, but that the conventional opposition between macro- and microanalysis (between global change and local action) is outdated. (Callon 1995, p. 58)

That is, the characterisation of science as a translation network interprets phenomena, artefacts and people together as actants; it rejects traditional distinctions between Nature and society, and between large-scale distinctions (science and society) and small-scale distinctions (such as the behaviour of experimental phenomena and the instruments that measure them).

The remainder of this chapter is structured around ways in which science is characterised by belief system or its elements.
2.3 The role of belief system in characterising a western European scientific tradition

The notion of a Western European scientific tradition can be characterised partly by the historical changes in belief systems. This tradition is discussed more fully in the companion chapter on context and Appendix B.1, but its mention here recognises the (changing) intellectual context within which all scientific work is done\(^2\). Tracing historical changes in belief systems shows that since antiquity there have been competing beliefs about the nature of the cosmos and our knowledge of it. Thus science history often contains conflicting beliefs, is not a linear sequence of single views of the world, and that some beliefs have been enduring in the history of science down to the present day.

For members of western European cultures this complexity may not be apparent, but the present section will highlight some belief systems that, mostly, share a belief that the cosmos is subject to human inquiry through sense data, and that the inquiry itself is subject to rational analysis, debate and modification. Belief in some regularity in the cosmos allows a degree of confidence in making generalisations from experience (sense data) and in making predictions. The examples also illustrate a second and related recurrent theme identified by Oldroyd (1989), the attempt ‘to establish some kind of correspondence between thoughts and things’ (p. 4). Study of the history of science highlights the importance of various historical belief systems to the development of contemporary beliefs and, ultimately, to how we characterise science; as historical analysis develops, so to does our understanding of science, in this case the development of scientific belief systems (Christie 1990; Matthews 1994).

The emergence of a particular belief system in Greece c600BC

The beginning of the western European scientific tradition is characterised partly by the emergence of a different belief system: a distinctive world view or views as one or more of a number of competing systems of beliefs about the universe or cosmos. Although some authors discern elements of what is characterised now as science in even the most ancient civilisations, most accounts characterise the Greeks, and more specifically the Ionians, as the first to theorise about how scientific ideas developed and how these ideas influenced beliefs in the general culture (Singer 1959; Hutton 1962). Thus Thales of Miletus (c624-546 BC) is the first person we know to have held a ‘belief in the constant and universal sequence or cause and effect in the material world’ (Singer 1959, p. 34). The significance

\(^2\) One interpretation is that all of science is (a) belief system and (b) context. To reduce the characterisation to one or two dimensions misses the point of a multidimensional characterisation, which is that scholars characterise science in different dimensions, or with different foci or emphases. The possibility of a satisfying characterisation based only on belief system or context does not represent characterisations of science by it structural features, for example, or its aims and purposes. The more accurate representation is that belief system is one of several dimensions used in the metascientific literature.
of Thales was that he attempted to explain Nature by the natural and not the super-natural, to see Nature as dynamic rather than static, to make clear the value of systematic observation as a basis, and to show the possibility and value of mathematical representations (Singer 1959, pp. 13-17).

Thales was able to compare and draw on a number of belief systems and knowledges. The Greeks of his time had inherited knowledge bases from a variety of cultures: mathematics, astronomy, botany and zoology mainly from the Babylonians and Egyptians. As a merchant and traveller, Thales observed that the deities worshipped in various cultures as supreme and omnipotent were in fact specific to each culture only. He thus sought to explain change and variation in the world by natural causes, and not by supernatural intervention:

As with every Ionian thinker, the ultimate object of the thought of Thales was to find a formula for all things. He thus set himself the task of discerning constancy amidst the diversity and variety of nature. This is but to say that his science was a part of his philosophy. To the general question 'Of what is the world made?' he would answer 'Water', meaning thereby some mobile essence, changing, flowing, without distinctive shape or colour, yet presenting a cycle of existence passing from sky and air to earth, thence to the bodies of plants and animals, and back to air and sky again. (Singer 1959, pp. 16-17)

This change in underlying belief marks a separation of thought from other cosmologies of the time that is commonly characterised as beginning the western European scientific tradition. While the particular idea is clearly no longer current, the significance is that it represents an attempt to seek some natural, underlying basis from which all the change and variation can be explained. For example, Gale (1979, pp. 12-13) has argued that these early beliefs have a partly scientific character because they entail a world view or belief system in which reality is ultimately accessible through normal, natural processes or perceptions; that is, a naturalist view. It was a break from non naturalist approaches, that entailed belief that the world required the action of gods, that reality is ultimately inaccessible to (transcends) normal human perceptions. The explanation of all change and variation by a single principle or ultimate reality philosophy now describes as a monistic explanation (Kreyche 1984). The attempt to improve our understanding of Nature by the reduction of many theories to a single coherent theory has continued as a strategy from Thales down to the present (Aronson 1983, p. 365). Also, Thales was able to demonstrate the value of careful observations of Nature, by which he impressed the Ionians with accurate astronomical predictions (learnt in Mesopotamia), and of mathematics, by which he made practical, not just theoretical, generalisations of Egyptian geometry.

Further, Thales' contribution was not left as an isolated piece of work. It would be reasonable to speculate that in an unsympathetic context - say, opposition from academic or church authorities - Thales' work would have amounted to nought. Some histories claim
that this was the case in other cultures. But, it is claimed, this did not happen in Greece at that time. Instead, a tradition emerged where such ideas were debated and alternatives proposed. Where Thales proposed water as the ‘first principle’ of Nature, for Anaximander it was the *apeiron* (an indefinite and infinite entity), for Anaximedes it was *air*, for Heraclitus it was *fire* and for Pythagoras it was *circling stars* (Singer 1959, p. 69). Thus, instead of being confined to the assumptions of a single belief system, the Ionian philosophers of the seventh and sixth centuries BC. established a tradition of seeking naturalistic explanations and proposing and debating competing cosmologies:

According to Aristotle, the characteristic of this Ionian cosmology is the fact that whenever its devotees asks the question: ‘What is nature?’ they at once convert it into the question: ‘What are things made of?’ or ‘What is the original, unchanging substance which underlies all the changes of the natural world with which we are acquainted?’ (Collingwood 1945, p. 29)

Collingwood identifies in this transformation three principles. The first two are ‘indispensable presuppositions of any “science of nature”’: first, there are natural things, that is, things not made by humans; second, these natural things constitute a single world of *Nature*, that is, that these things can also be identified positively by general statements. The third principle is peculiar to the Ionian school of thought, that what is common to these natural things is that they are made of a single substance or material (Collingwood 1945, pp. 29-30), such as water or air. These are significant statements of a belief system, more significant and enduring than individual propositions that water or air are the actual principles.

This scientific tradition became, in effect, a tradition of proposing, clarifying and debating various metaphysical beliefs: that is, one of using language and refining concepts. Jaki (1974) has argued that, although their methods are often lost to us, Greek thinking was characterised by clearly formed beliefs and concepts that allowed clear choices:

The word ‘atomic’, which our age uses as its hallmark, has an ancestry leading back to Pericles. Then and there it was clearly perceived that matter had to be either discrete or continuous. Decision on this represented the touchstone of truth for Democritus as well as for Aristotle. In the latter’s words the verification of a strictly smallest quantity could be of such portent as to shake the very foundations of philosophy.

Ancient Greek philosophers showed equally keen interest in questions having to do with the very large. There again, a fundamental pair of alternatives was formulated with all possible clarity: the world could only be finite or infinite in extent. (Jaki 1974, p. vii)

For Jaki, this clarity was characteristic of early Greek thinking and not of other cultures: he characterises the concepts *li*, the *yin* and the *yang*, for example, as inherently vague, which he interprets as having inhibited Chinese science. While Jaki’s analysis is somewhat Eurocentric, the point here is that his analysis is based on fundamental ontological beliefs: beliefs about the ultimate nature of matter and the formation of clear ontological alternatives.

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3 See discussions in section 2.12, below, the companion chapter on context and Appendix B.1.
However, Collingwood has argued it was not sufficient that the Ionians asked questions: what was being asked was also important. In this respect, the Ionians 'failed' and the beginning of a scientific tradition lies more clearly with Aristotle. The ultimate 'failure' of the Ionian school of thought was that they were committed to answering questions that no refinement of experimental technique could ever answer:

1. How can we form a clear mental picture of the universal primitive substance?
2. How, from this primitive substance, can we deduce the world of nature? (Collingwood 1945, p. 43)

Nonetheless, this inquisitive attitude and the ontological beliefs such an approach entails serve to characterise science:

The history of science, in so far as it is a history of scientific progress, consists not so much in the progressive accumulation of facts as the progressive clarification of problems. What makes a natural scientist is not his knowledge of facts about nature but his ability to ask questions about nature: first, to ask questions at all, instead of waiting to see what turns up; and secondly, to ask intelligent questions, that is, answerable questions: intrinsically answerable questions, as distinct from nonsensical questions ... (Collingwood 1945, p. 42)

That is, this approach implies an inquisitive attitude, which reflects a basic belief that the cosmos is open to such interrogation. On this view, beliefs about the nature of reality and the way in which humans can articulate with this reality characterise the emergence of the Western European scientific tradition. Two and a half thousand years later, it is the basic beliefs and orientations of the Ionians that are more recognisably science to us than their particular explanations or methods of inquiry.

**Plato's belief system: beliefs, knowledge and being**

We will confine the present summary of scientific beliefs in antiquity to two later thinkers who had tremendous influence on the history and philosophy of science: Plato and Aristotle. The contributions of Plato (427-347 BC) and Aristotle (384-322 BC), a student of Plato's, have been significant and enduring in the Western European scientific tradition:

[T]he themes stated by Plato and Aristotle have recurred repeatedly and are represented even today by two rival approaches (to the philosophy of science) - one (Platonic) based in logic, the other (Aristotelian) based in the history of science. (*Encyclopaedia Britannica* 1982, 16-377)

Their own writings and the literature addressing their work are far too extensive to cover here, and we will simply mention some beliefs about the cosmos and our knowledge of it, drawing on general science histories (Singer 1959; Charon 1970; Ronan 1982; entries in Bynum, Browne & Porter (eds) 1983; Harré 1986; Oldroyd 1989).

Like the Ionians and others who followed them, Plato also sought to explain the apparent uniformity that underlay changes in Nature by proposing a single principle of reality (Oldroyd 1989, p. 6). But Plato was particularly concerned to separate what constitutes knowledge (*episteme*) from opinion (*dogma*). For Plato, the world we perceive...
with our senses - the world of opinion - comprises change and variation, and the senses can be deceived by illusions of other reasons. However, the world of Ideas - the world of the intellect - contains true knowledge which is real, unchanging and certain. Plato therefore proposed that reality is based on forms or Ideas, not material bases like water or air that the Ionians had proposed: for Plato, reality exists in a transcendent domain of ideas or forms and not in the material world that we perceive. Objects in the material world are only copies of the perfect forms, which accounts for the variations between similar objects as we perceive them. The basis for this account was geometry, in which we understand the concepts of perfect geometric figures and recognise our attempts to draw them, even though the drawn figures are accepted as never being perfect. So it is with the objects we observe. We may observe physical objects, but we only have belief or trust; we may observe replicas of objects, which are even less real, but we only have imaginations or delusions. We may make a correct judgement based on sense data, but that is not knowledge; knowledge would be the apprehension of the form or Idea. We can understand mathematical entities, by mentally representing them; even more securely, we can know forms or Ideas through dialectical discussion. Plato gives several accounts of how we apprehend the perfect Ideas (Oldroyd 1989, pp. 8-15). In the Symposium he suggested becoming familiar with examples that represent the Idea - beautiful objects to apprehend more closely the Idea 'beauty', for example. In the dialogue Meno he suggested that we have some a priori or innate knowledge, of which it is the task of education to draw out. In the Republic he set out a scheme in which one can ascend from mere opinion (doxa) to true knowledge (episteme), through parallel states of knowing - epistemology - and equivalent states or levels of being - ontology.

Plato believed ideas to be real, and in this sense his theory is an example of realism (Bhaskar 1983k). However, over the course of his writing, Plato's reality changed from the material cosmos to an ideal realm existing apart from the material cosmos, that is, a transcendent reality (Oldroyd 1989, p. 8). Because these ideal forms came to be thought of as existing separately from the material world Plato’s cosmology can also, and is more usually, considered to be an example of idealism. To the extent that Plato proposed that knowledge is to be deduced from sound first principles, his theory is also an example of rationalism. Plato’s writings marked the beginning of a strong tradition in philosophy whose influence has remained down to the present, and indeed Whitehead called all Western philosophy 'a footnote to Plato'. Because Plato’s theory downplays the contribution of observational data and his interest was mainly in mathematics he is largely set apart from those considered as scientists, although rationalism is found later in the history of science, and the methods of contemporary theoretical physicists, for example, have a strongly rationalistic element.

The writings of Plato raise matters of enduring philosophical interest in the role of beliefs in the Western European scientific tradition. One is whether idealistic or realistic
beliefs of the cosmos are better. Another is whether classes of objects, like Plato’s Ideas or forms, have a real existence or whether it is the individual entities that really exist. That is, whether or not the proper objects of our inquiry into the cosmos are universals or particulars.

Aristotle’s belief system: knowledge and being

Aristotle’s work is often characterised as more recognisably scientific than Plato’s (Singer 1959; Oldroyd 1989; Mollard 1990); this, and particularly his emphasis on observation, is discussed in Appendix B.5. However, it also applies to his belief system which, although complex, contained enduring elements. For instance, his beliefs about the nature of the cosmos and the ways knowledge might be gained of it are significantly different to Plato’s:

By accepting that physical matter was as significant as its Form or Idea, Aristotle defined a sphere of influence within which truly scientific work could be done. To this extent he was much more of a scientist than Plato, who saw no value in the investigation of matter. As a result, Aristotle built up a great deal of knowledge on all manner of subjects, including biology, astronomy and physics. To all these observations he applied his rigorous logical method, which inquired into the various causes of the things he observed; only one of these causes, the ‘prime mover’ did he consider to be beyond the scope of reasoned investigation. (Ronan 1982, p. 103)

That is, by turning around Plato’s ontology so that universals were individual objects rather than classes of objects, Aristotle enabled scope for a knowledge of objects, that is, science knowledge. Thus for Aristotle the universals exist in the objects or particulars that are perceived with the senses, not in Ideas. However, Bhaskar (1983k, p. 362) has characterised both Aristotle’s and Plato’s beliefs as realist in the sense of believing ‘the objects of scientific knowledge exist and act independently of the knowledge of them’.

Aristotle’s cosmology and physics was the basis for scientific explanation until the late Middle Ages, only replaced by the developments from Copernicus, Galileo and others that are characterised commonly as the Scientific Revolution.

Valuable scientific work was completed within the Aristotelian system (Singer 1959; Harré 1985). Much of the Aristotelian belief system encompassed existing beliefs, and it had undoubted successes in reconciling earlier disparate views and accommodating several philosophical problems that had arisen.

Belief in God

First, Aristotle believed in an omnipotent God who is perfect and the ultimate cause - the ‘unmoved mover’ of all physical bodies in both the heavenly and terrestrial realms. This is a departure from completely naturalistic belief systems and explanations of cause.
Belief in a principle of life (psyche or soul)

Secondly, he believed that living and non-living things are distinguished by a principle of life, or psyche, that is often referred to as soul (Singer 1959, p. 47). Harré (1985, p. 127) has argued that Aristotelians used the growth and behaviour of plants and animals as a descriptive analogy, not necessarily to label a belief that everything was alive and change was organic. In any event, this principle of life, or soul, served to orient and integrate the functioning of the organism towards a more perfect end. Belief in a principle of life is vitalism, and belief in a purposeful existence in which every part serves an end is teleology. In this respect he shared the cosmology of the ancient Greeks, for whom Nature was living and development was purposeful, i.e. teleological. Development was believed to be the process of becoming more perfect. These beliefs opposed the views of Democritus and his followers who explained the actions of all things in terms of the atoms of which they were made, which is a mechanistic belief. The opposition of vitalist and mechanist beliefs continued for two thousand years and 'has ceased to separate students of living things only in the twentieth century' (Singer 1959, p. 48).

Belief in perfection as a function of change

Third is a belief in perfection as the purpose of all change. Thus living things grow towards a more perfect state and terrestrial things move towards their correct place. The belief in the inherent beauty and perfection of the circle, and especially the celestial spheres, was held by the Pythagoreans:

Circular movement is perfect since the circle is the perfect figure. Circular movement represents the changeless, eternal order of the heavens. It is contrasted with rectilinear movement which prevails on this our changing and imperfect earth. (Singer 1959, pp. 53-5)

Thus in the Aristotelian tradition of belief, the Earth was at the centre of the universe, a widely-held and long-standing belief in many cultures. The Earth was also believed to be spherical, a belief held by the Pythagoreans. It also owed something to observations of ships going down over the horizon; that is, belief in circularity also had an empirical character. Aristotle's Earth, which was stationary at the centre of the universe, was enveloped by nine concentric, crystalline spheres, an idea developed from that of Eudoxus (c400-347BC). On the outermost sphere, which was also fixed, was found God, the 'unmoved mover' who caused movement both of the other spheres and on Earth. The other spheres carried the moon, sun, five planets and the stars. The innermost sphere, on which was the moon, marked the boundary between two realms - the ethereal above, where movement was circular and eternal, and the sublunar below, where movement was rectilinear and discontinuous.
Different terrestrial and celestial belief systems

Thus, fourthly, the physics of the terrestrial and celestial realms are different: they represent different metaphysical belief systems. The belief that two different physical systems operated was accepted at least as far back as the Pythagoreans. The sublunar region, being furthest from God, is imperfect, and subject to decay. The celestial bodies are moved continuously in perfect circles by the unmoved mover, God, and act as efficient causes of movement in the sublunar realm. Change in the sublunar region is also caused by the interaction of matter, and is accounted for in terms of matter comprising four elements in the sublunar region, each of which having qualities. These qualities cause much of the change in the sublunar world, change being for the end of attaining perfection, either in substance to a perfect Form, or the return of an object to its natural resting place.

Fifthly, Aristotelian physics is different from his biology, which is much more empirical, as we have noted; this is partly a difference in beliefs about knowledge and the material world.

Sixthly, Aristotle believed that the whole cosmos is made of a basic and universal matter, which is continuous, unlike the atomism of Democritus.

Seventhly, matter comprises elements, whose properties are given by combinations of qualities. Aristotle accepted the theory of Empedocles (c492-432 BC) that matter is made of four elements, or unchanging substances: earth, fire, air and water, and that other substances comprise mixtures of these four. Interactions of these elements accounts for change and decay. The unchanging perfection of the celestial realm, which is predicated partly on observations of little change over long periods of time and partly on the belief that it is near to God, was accounted for by Aristotle adding a fifth element, the aether, which exists only in the celestial realm. The appearance and behaviour of the four elements in the sublunar realm are represented by their qualities or natures. The four active qualities, hotness, dryness and their opposites, were later added to as ad hoc explanations by later scholars, revealing an inherent flaw in Aristotle’s system of explanation. Eighth, the universe is finite in space, since it is bounded by the outer sphere, but is infinite in time, since it can be neither created nor destroyed (Singer 1959, p. 55).

Beliefs about knowledge, language and being

Aristotle also distinguished between thinking about things and putting into language what we think about these things, so distinguishing knowledge (epistemology), statement (language) and being (ontology); this has been an ongoing interest in metascience down to the present (Amadio 1974, p. 1169). The belief that knowledge, language and an ontology are linked also comprises an ongoing debate in western philosophy, although again for Oldroyd, Aristotle’s account is not satisfactory:
On the one hand, forms were immanent essences; and on the other they were expressed in terms of verbal definitions. There was a most unfortunate conflation of logical and ontological properties. Language and reality were supposed somehow to be in a state of correspondence, one with another, so that the physical features of the world could be elucidated by linguistic analysis. Aristotle did, however, lay emphasis on the need for empirical inquiry. (Oldroyd 1989, pp. 25-6)

Nonetheless, Aristotle’s linking of knowledge, being and language remained an important characteristic of later belief systems in this scientific tradition. The union of knowledge, language and ontology is reflected in Aristotle’s view of what knowledge we can gain of things. In the Categories, one of the works comprising the Organon, Aristotle proposed ten categories of what we can know, such as Substance, Quantity, Place, Time and Relation (Oldroyd 1989, pp. 16-7). These categories contributed to an ongoing philosophical interest in categorising metaphysical qualities; for example, they were later developed into a very influential thesis by Kant.

Beliefs about the empirical interrogation of Nature

Both Singer and Oldroyd emphasise Aristotle’s plea for empirical inquiry: Aristotle ‘advises his readers to compare his views with those that they themselves reach’ (Singer 1959, pp. 55-6). The separation of celestial and terrestrial physics meant that the celestial realm, and the laws regulating movements in it, was beyond the experimental examination of humans. In other respects, Aristotle advocated empirical inquiry as the means to knowledge of the material world, although the rise of a scholastic tradition of adherence to existing ideas was more influential in the pre-eminence of Aristotle’s world view in Europe for two thousand years. See the historical section in the companion chapter on context, and Appendix B.1.

The demise of the Aristotelian belief system

The eventual demise of the Aristotelian system was slow and piecemeal, and can be characterised partly by fundamental beliefs, both flawed Aristotelian beliefs and the rising influence of several competing belief systems:

About the middle of the seventeenth century there were four different currents of thought about the structure of matter existing side by side and partly blending with each other:

(1) The peripatetic [Aristotelian] doctrine of the four elements, in which, however, the originally essential feature of homogeneity of the minima naturalia was already beginning to lose ground to the conception that the smallest particles of a chemical compound are aggregates of independently subsisting particles.

(2) The doctrine of the three principia or tria prima (salt, sulfur, mercury), originating from Paracelsus and referred to as the Spagyristic doctrine.

(3) The Cartesian doctrine that matter is identical with extension, but that it exists in three degrees of fineness.

Bhaskar has argued that the lack of clear and consistent beliefs upon which a conceptual framework could be built led to unsatisfactory, ad hoc theorising in Aristotelian natural philosophy. This became increasingly evident as alternative belief systems emerged:

But the [Aristotelian] system lacked a clear criterion for intellectual intuition, which facilitated its dogmatic degeneration in the Middle Ages. It also lacked any principle of composition of the constituent elements, such as could perhaps have been provided by the development of Democritus' brilliant atomism. This resulted in a loss of explanatory power, as forms proliferated in the wake of the identification of more and more kinds of matter - to the ridicule of the 17th-century atomists such as Boyle.

Aristotelian metaphysics gradually broke down under the impact of the development of the non-anthropomorphic, quantitative, mechanistic and non-teleological conception of Nature associated with Copernicus, Galileo, Newton and Darwin ... The theory of causality gave way to the positivism of Hume and the transcendental idealism of Kant. (Bhaskar 1983a, p. 27)

That is, the beliefs that underpinned Aristotelian science were replaced by other beliefs: the cosmos was no longer believed to act according to human characteristics; the cosmos could be well represented mathematically; a mechanistic metaphor was more helpful rather than an organic one; and, as a result, natural change was neutral in the manner of a mechanism rather than purposeful in the manner of organic development.

Natural philosophy belief systems in the Middle Ages

There was some development of the Aristotelian system by Islamic scholars during the Middle Ages, but it declined in Europe, largely due to the displacement of secular philosophy by the Christian Church. Collingwood (1945, p. 93) characterises this as 'a sustained polemic against the medieval thought inspired partly by Aristotle and partly by the philosophical views implicit in the Christian religion'. Dijksterhuis (1986, p. 100) has argued that scholarship in Europe was essentially restricted to the monasteries from around AD529, when the Emperor Justinian closed the 'last school of pagan philosophy in Athens', to at least the twelfth century. He characterises mediaeval science in Europe as a 'subordination' of science to theology, in 'a period of profound intellectual decline' (p. 100). That is, this period in Europe can be characterised as a period in which the ontological claims inherent in a Christian belief system were valued over the ontological claims of the extant Greek secular writings. This is known as scholasticism:

*scholasticism:*
Servile adherence to the methods and teaching of the schools; narrow or unenlightened insistence on traditional doctrines and forms of exposition. *(Shorter Oxford Dictionary 1973)*

It is related to, but more general than, the term *Scholasticism*, sometimes distinguished, as here, by the use of upper case:

*Scholasticism:*
The doctrines of the Schoolmen; the predominant theological and philosophical teaching of the period AD1000-1500, based upon the authority of the Christian Fathers and of Aristotle and his commentators. *(Shorter Oxford Dictionary 1973)*
This represents the teachings of Aristotle as they became better known and as interpreted by Thomas Aquinas.

Thus the rise of *scholasticism* is characterised partly by a belief that reliable knowledge of the cosmos is to be gained from the accuracy of encyclopaedic transcriptions and compilations of what remained of ‘the final phase of ancient culture’:

This purely receptive assimilation of what had been handed down was to be all for the time being; the intellectual powers of the western world were not yet developed far enough to be capable of independent scientific work, nor did the sources of Antiquity as yet flow abundantly enough to reveal ancient science in all its wealth. (Dijksterhuis 1986, p. 101).

As a consequence of this reliance on the authority of texts, the empirical basis for knowledge became less valued, and typically this period is characterised as less scientific.

Other belief systems were also influential by the sixteenth century, especially magical and mystical accounts of Nature, such as in alchemy and Hermeticism (Sheppard 1983, pp. 9-10; Keller 1983a, pp. 184-5). For example, Dijksterhuis (1986, p. 280) characterises the ‘fundamental principles of hermetic thought’ by ontological beliefs: human nature and form embodies the nature and form of the cosmos (*parallelism of the macrocosm and microcosm*); different entities within the cosmos exhibit causal sympathies or affinities with other entities (*cosmic sympathy*); and the cosmos is living and has a soul (*the living universe*). This serves as a reminder that the history of science is not characterised by a strictly linear succession of unique belief systems: at every stage there are many belief systems competing, some alike, some not. The emergence of ‘classical science’ in the Renaissance could therefore be characterised as the replacement of one collection of belief systems with another. To this should be added the observation that for most authors the difference before and after about the seventeenth century is far greater and more significant than within either of the ‘Aristotelian’ or ‘classical’ eras. Moreover, for Dijksterhuis (1986) the shift in beliefs that characterise the Scientific Revolution was far more significant than the shift from classical to modern science. The status of the Scientific Revolution is evaluated in Appendix B.1, but it is certainly the case that many beliefs and assumptions that still have meaning in science today date from the seventeenth century, whereas few date to before that.

*Changes in belief around the seventeenth century*

Historians who emphasise the change in the Scientific Revolution, rather than long-term continuity, do so partly by shifts in beliefs about Nature and how reliable knowledge could be gained of it. That is, different metaphysical systems were proposed and new epistemological possibilities emerged. Indeed, for Bronowski (1978, pp. 22-3) it is the shift in belief systems that marks this period as an episode of significant change. He therefore rejects the claims of some historians of science, such as Thorndike (1923-58), who downplay the notion of a *scientific revolution* and draw attention to the continuity from
before the Middle Ages down to the present day. To represent this period largely in terms of the continuities gives ‘a false perspective of the great threshold from which the burst of modern science comes’. Especially, it fails to highlight the importance of the fundamental metaphysical beliefs, and the attitudes and orientations they entail:

(There) are in magical and particularly alchemical practices many techniques which later formed an important part of technology and experimental science. Now that’s undoubtedly true. But alas, in my view, this has nothing to do with the case. Of course there were people of all kinds practising all kinds of alchemy right up to the days of Newton, whose alchemical writings are so voluminous that they were never published. Nevertheless, my main interest is in their attitude toward how the world works and how you make it obey, and not at all in their discoveries of how you smelt this or make that process in metallurgy work. (Bronowski 1978, pp. 22-3; emphasis added)

The present thesis interprets Bronowski to be arguing here that particular knowledge outcomes and experimental activities alone do not distinguish science from alchemy or magic, but such a distinction can be made in terms of belief systems, in particular beliefs about how the world works and how you make it obey. The present thesis extends Bronowski’s idea to argue that we distinguish science by its characteristic belief systems in combination with activities, knowledges, contexts, structures and purposes.

A number of metaphysical systems were proposed or contributed to by individual scientists and philosophers, including Harriot, Galileo, Descartes, Boyle, Locke, Hooke, and Newton. Accounts which seek to underline the significance of these changes draw attention to the shifts in the underlying beliefs - mostly ontological and epistemological beliefs, and other, related, beliefs. For example, Collingwood has characterised the development of a general Renaissance cosmology which differed from that under the previous, Aristotelian system, largely in terms of shifts in metaphysical beliefs:

The Renaissance view of nature began to take shape as antithetical to the Greek view in the work of Copernicus (1473-1543), Telesio (1508-88), and Bruno (1548-1600). The central point of this antithesis was the denial that the world of nature, the world studied by physical science, is an organism, and the assertion that it is devoid both of intelligence and of life. It is therefore incapable of ordering its own movements in a rational manner, and indeed incapable of moving itself at all. The movements which it exhibits ... are imposed upon it from without, and their regularity is due to ‘laws of nature’ likewise imposed from without. Instead of being an organism, the natural world is a machine ... The Renaissance thinkers, like the Greeks, saw in the orderliness of the natural world an expression of intelligence: but for the Greeks this intelligence was nature’s own intelligence, for the renaissance thinkers it was the intelligence of something other than nature: the divine creator and ruler of nature. This distinction is the key to all the main differences between Greek and Renaissance natural science. (Collingwood 1945, p. 5)

Several shifts of beliefs are given or implied in this passage: the decline in the belief of Nature as organismic, and with it beliefs about causality, the decline of beliefs that nature is ensouled, and a change in beliefs about the relationship between Nature and God. Needham (see summary statement 72) makes similar references to beliefs: the nature of reality and the
ability to represent it mathematically; experimentation as a surer way to gain knowledge of Nature; a revision of beliefs about metaphysical entities; and the usefulness of a new model of reality. This last point has its own special interest because the mechanical model of reality became discredited during the twentieth century, i.e. among physicists at least this belief is no longer held. Yet Needham, writing in 1969 and drawing on the historical, philosophical and sociological theorising up to that time, still claimed that the adoption of that model contributed to the shift from one scientific belief system to another which retains some modernity down to the present. This raises some interesting questions: was the mechanical model a necessary part of the development of Western European science, and if so, is it a necessary part of the development of science in general? Did it instead serve some other function in the development of ideas, or perhaps serve no particular function, i.e. that its use was coincidental but not causal? These questions and others contribute to a larger debate about the nature of science which the six companion chapters address as a set. The important point here is to draw attention to the use of belief systems, by Collingwood, Needham and others, in characterising this significant period in the history of science. Some beliefs that form part of these arguments are detailed in the remainder of the present chapter, including section 2.11 on models and metaphors.

The considerable change in belief systems at the time of the Scientific Revolution is marked by various terms: the ‘Corpuscularian philosophy’ (as by Harré) and the ‘Renaissance view of Nature’ (as by Collingwood). It is the belief systems that arose in this period that are quite evidently antecedent to modern science. For Oldroyd (1989, p. 49) the period is significant partly because the developments from that time retain some currency down to the present whereas the science from earlier times have been largely superseded. In large measure the science of Aristotle, Galen and Ptolemy strike us as the study of history. For Bronowski (1978) it is more than this: whilst some features of ‘science’ from the ancient Greeks had persisted, the ‘Scientific Revolution’ - particularly the advent of Baconian science - marked a fundamental departure from belief systems (often characterised as mythologies). It is fundamental changes in belief system such as this that Kuhn later described as a paradigm shift.

Because the beliefs dating from the Scientific Revolution down to the present are more complex and developed from a great many figures over an extended period, we will address belief systems from that time thematically in the sections that follow: causality, attitudes to Nature, beliefs in magic and in God, mathematics, metaphysics, and the use of models and metaphors.
2.4 Beliefs about cause

Notions of cause and effect are central to science, and a scientific world view is commonly characterised as having beliefs of cause and effect that are distinct from other world views or belief systems (see, for example, Johnston 1986). The present section highlights some beliefs about cause that characterise science or scientific belief systems. Discussion of various theories of cause, and the seeking of causal explanations as a long-standing purpose of science, is given in the companion chapter on purpose and Appendix B.3. Aristotle’s theory of cause, for example, is interpreted here as contributing to a system of belief about the material world.

In Aristotelian science a thing or event was believed to arise from four kinds of cause: the material from which something is made, as in the bronze of a statue (material cause); the form or organisation, as in the form of bronze as a statue (formal cause); the agent that brings something about, as in the sculptor of a statue (efficient cause); and the sake for which something happens, as in the purpose of a statue, such as a representation (final cause). Aristotle himself noted that there was a tendency for the formal, efficient and final causes to merge, as in the case of reproducing species (Molland 1990, p. 562). These beliefs about cause have been interpreted as beliefs that enable scientific inquiry:

The Aristotelian insistence on both formal and material causes is of considerable significance because it gave form a degree of independence from matter not found in more mechanical views of nature, where the tendency was to explain everything in terms of the arrangement of material particles. Aristotelian science was far less reductionist, and for that reason could be accused of appealing to occult virtues, properties of bodies that had to be accepted as brute facts, not explicable in terms of something supposedly more intelligible. (Molland 1990, p. 562)

Occult virtues, as we shall mention later, were properties that could be inferred, and hence were not subject to empirical test, such as gravity, levity and magnetism. However, later scholars, particularly the Hermetic philosophers in the Middle Ages, proposed occult virtues as empty, ad hoc explanations of every puzzling phenomenon, such as the dormative virtue of opium (Heilbron 1983d). It was belief in formal causes, meaning that the form of a body gave it its qualities, that enabled belief in occult properties.

However, it was the metaphysical belief that Nature tended to develop towards unrealised perfect forms, that is, an ontological belief that change in Nature is teleological, that became most objectionable to later thinkers. In the sixteenth century teleological explanations came under attack from several quarters, including Francis Bacon, who realised that to explain a cause as a tendency towards that effect is no explanation at all (Collingwood 1945, p. 93). A different belief emerged of how Nature changes:

The assumption that change must be explained [by the action of material things already existing at the commencement of the change] is already a conscious principle in the philosophers of the sixteenth century. Thus Bernardino Telesio, in
the middle of the century, regards nature not as drawn onwards by something outside itself to imitate forms having an eternal and immaterial existence, but as possessed of an intrinsic activity of its own, namely heat, in virtue of which it generates motion in itself and thus produces all the various types of structure found in the natural world. (Collingwood 1945, p. 94)

This represents two significant changes in belief. One is that causes were believed to reside (or were immanent) in Nature, rather than outside Nature (or transcendent); this belief encourages empirical study of particulars, a significant characteristic of modern science. The other change in the account of causation was from a teleological account of four causes to two causes, being formal and efficient causes only. Both accounts of cause are based on ontological beliefs, provided by organismic and mechanistic metaphors respectively.

The influence of Hume on beliefs about cause

The most influential account of cause since the Scientific Revolution has been Hume’s (Sanford 1995). Hume’s notion of cause is usually interpreted as entailing several beliefs: (a) causes and effects are events; (b) the causal event is prior to, or at least concurrent with, the effect event; (c) cause and effect are close in time and space; and (d) cause and effect have a necessary connection (Quinton 1988, p. 113). In post-Humean philosophy, however, Sanford characterises only (a) as a majority view. (b) is a controversial view because it commonly involves a circular argument: to say that an event is first because it is the cause is circular if we then say it is the cause because it is first (Sanford 1995, p. 80). (c) is opposed by a prevailing view that continuous causal paths connect causes and effects: many causes and effects are not close in time and space, such as light switches and electric lights which may or may not be immediately close.

There is at least one other implicit belief in this and most other beliefs about cause: that Nature exists continuously through causal changes:

It is often assumed in physical theories that the points of space and time are continuously ordered, and that physical processes may be represented by continuous functions. (Bostock 1983b, p. 79)

This is known sometimes as the Law of Continuity, but the problem is that it does not seem to explain cause in quantum physics:

According to the Law of Continuity any quantity in passing from one magnitude to another must pass through all intermediate magnitudes of the same class. The a priori proof of this law is that discontinuous action is not compatible with the concept of continuous time.

The Copenhagen interpretation of quantum events rejects both the notion that all changes require explanation and that particles conform to the Law of Continuity. Discontinuous action, annihilation of elementary particles, whether stable or unstable, and the radioactive decay of nuclei are all taken as basic and needing no explanation, when in fact such changes and violations of spatial indifferences are precisely what ordinarily and in all other areas of science would require explanation. (Madden 1983, pp. 55)

That is, the beliefs about cause and effect that apply to explanations in both everyday events and in classical physics do not seem to apply in quantum physics. Finally, (d) can be
interpreted in several ways in post-Humean philosophy: it is a prevailing view among philosophers that $a$ is necessary for $b$ if and only if $b$ is sufficient for $a$, but it is a controversial view that 'a totality of conditions necessary for an occurrence is jointly sufficient for it' (Sanford 1995, p. 82). Scientific beliefs about cause contribute to beliefs about Nature, God and magic, among other things. These are also taken up in this appendix; as noted above, some philosophical views of cause are discussed in the companion chapter on purpose and Appendix B.3.
2.5 *Attitudes to Nature*

Beliefs about the material world, or cosmos, are characterised commonly as beliefs about *Nature*, although this term has two related uses:

In both Greek and Latin the words for Nature (*physis*; *natura*) were etymologically connected with the idea of genesis of birth. In neither case, however, did the root-idea persist; rather, the concept of Nature developed in a two-fold fashion, referring (a) to the essence or nature of a thing or type of thing, and (b) to the world at large, particularly to the physical or 'natural' world. Both uses are in Aristotle (383-322 BC) ... Both senses presuppose a contrast between what exists by 'by nature', or 'naturally', and that which does not; in the one case the latter is the merely accidental or conventional, whereas in the other one, natural is distinguished from supernatural (and 'a state of Nature' is distinguished from 'a state of Grace'), or is distinguished from that which has arisen through human actions. (Mandelbaum 1983, p. 289)

Mandelbaum notes that the two senses are related, but nature as *an essence of things* tended to characterise Classical and Mediaeval science, while Nature as *the physical world* has tended to characterise science the Renaissance. We will confine our attention here largely to the second view, of Nature as the material world or cosmos.

We have mentioned attitude(s) to the cosmos, or material world, as part of a scientific belief system: the literature describes various attitudes, entailed by the Aristotelian-Islamic belief system, in the beliefs that emerged in the Scientific Revolution, and subsequently down to the present. The present section will highlight some distinguishing features of each of these, and the later section on beliefs in other cultures will clarify some of these as they have been used to characterise the western European scientific tradition.

*Mystical attitudes to Nature*

Collingwood has argued that even in the sixteenth century, European beliefs about Nature encouraged a mystical attitude or orientation to Nature. In the Aristotelian tradition, the fundamental ontological beliefs that Nature was ensouled and teleological implied epistemological beliefs that knowledge of the cosmos was revealed and magical. Nature in the Aristotelian tradition was believed to be:

a material imitation of a transcendent immaterial model, [implying] that some things in nature were accidental ...

But [in the fifteenth century] nature was still regarded as a living organism, and the relation between nature and man [sic] was conceived in terms of astrology and magic; for man's mastery over nature was conceived not as the mastery of mind over mechanism but as the mastery of one soul over another soul, which implied magic; and the outermost or stellar sphere was still conceived in Aristotelian fashion as the purest and most eminently living or active or influential part of the cosmic organism, and therefore as the source of all events happening in other parts; hence astrology. This magical and astrological conception had powerful

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4 This is designated in the present thesis by the capitalised form, Nature; capitalisation in quotations, however, is left as in the original, whichever is used by the author.
enemies from the first, notably Pico della Mirandola, ... Savonarola and Calvin; but in spite of this, the fifteenth and sixteenth centuries were predominantly given over to these occult sciences, which only died out by degrees, and died very hard, in the popular witchcraft of the seventeenth and eighteenth centuries. (Collingwood 1945, pp. 95-6)

The changes to this view were highly significant, and were based on fundamental beliefs about the cosmos: the decline in the belief of Nature as organismic, as having a soul, and with these, the decline of magical beliefs. (We will examine magical beliefs in more detail in Section 2.6 below).

Mandelbaum (1983) noted that Nature as the material world is also used either as the aggregate of that world minus voluntary human action, or 'it can also refer to whatever underlying physical forces or laws are believed to account for that which occurs' (p. 290).

Some accounts have personified the power of Nature:

But even when such a personification has been rejected, as by Descartes (1596-1650), Nature has been viewed as a unitary power or force governing all phenomena through unchanging principles or laws. (Mandelbaum 1983, p. 290)

This was a view held by the Hermetic tradition of alchemists, who shared with the Aristotelians a belief that Nature was a living whole. However, the belief in laws as governing principles was ultimately successful as part of the mechanistic belief system:

The mechanistic philosophy identified the laws governing the physical world with the laws of mechanical action, and Nature as the aggregate of all things was viewed as a great machine. The parts of that machine, like the parts of man-made [sic] machines, were assumed to act because of their configurations, the contacts between them, and the transfer of motion from part to part. Excluded from the explanation of natural processes were appeals to purposive action, to secret powers and vital forces; a strict mechanical determinism was believed to hold throughout the natural world. (Mandelbaum 1983, p. 290)

The significance of Copernicus' belief system

A significant contribution to the change in these beliefs was Copernicus's alternative account of the solar system, De revolutionibus orbium coelstium, published posthumously in 1543. Its displacement of the Aristotelian-Ptolemaic conception of the earth at the centre of the universe by a heliocentric solar system is one of the best-known episodes in the history of Western European science, but for Collingwood its real significance is a change of belief and attitude, which is usually under-appreciated:

The philosophical significance of this new astronomy was profound, but it has often been misunderstood. It is commonly said that its effect was to diminish the importance of the earth in the scheme of things and to teach man [sic] that he is only a microscopic parasite on a small speck of cool matter revolving round one of the minor stars ...

... The true significance of his astronomical discoveries was far more important. It consisted not so much in displacing the world’s centre from the earth to the sun as in implicitly denying that the world has a centre at all ... Its real point was that the material world has no centre; and this was rightly regarded as a revolution in cosmology, because it destroyed the entire theory of the natural world as an organism. An organism implies differentiated organs; in the spherical
world-organism of Greek thought there was the earth in the middle, then water, then air, then fire, and lastly, for Aristotle, the *quinta essentia* of the world's outermost envelope; now, if the world has no centre, the very basis of these differentiations disappears; the whole world is made of the same kind of matter, the law of gravitation applies not only in the sublunary regions as Aristotle thought but everywhere, and the stars, instead of having a divine substance of their own, are homogeneous with our earth. This idea, so far from diminishing the scope of man's powers, vastly enlarged it; for it taught him that scientific laws established by him on earth would hold good throughout the starry heavens. It was directly owing to Copernicus's denial of geocentric astronomy that Newton could imagine the force which kept the moon in orbit to be the same that drew his apple to the ground. For Aristotle, nature is made of substances differing in quality and acting heterogeneously: earth naturally moves towards the centre, fire away from the centre, and so forth. For the new cosmology there can only be one substance, qualitatively uniform throughout the world, and its only differences are therefore differences of quantity and of geometrical structure. (Collingwood 1945, pp. 96-8)

This passage is a clear statement of changes in beliefs and attitudes from a different belief system. First is the ontological belief that the earth orbits an unremarkable star, our sun. From this follow a number of attendant beliefs, such as the universal applicability of physical laws derived on earth, and attitudes, such as an inquiring attitude concerning the heavens. Although more recent accounts judge Collingwood's depiction of the cause of the decline in the belief of an organismic cosmos is an oversimplification (see for example Schuster 1990), the beliefs and assumptions are clear.

*The mechanistic world view*

The (historically) rapid and complex rise of a mechanistic world view is well documented. For example, Dijksterhuis (1986) gives a technically detailed account of the mechanisation of the world picture from Pythagorus to Newton, that also argues for a new attitude to Nature emerging at this time. Dijksterhuis gives accounts of contributions from mechanics, astronomy, philosophy, theology, social changes, and individual personality, to name some, in the development of a mechanistic world view. For all these reasons, the mechanisation of the world picture appeared to be a more useful conception than the organismic one. Mandelbaum (1983, p. 291) traces historical interest in several themes arising from the mechanistic belief system. For example, most scientists and Enlightenment philosophers took mechanism to be an explanatory principle of the physical world, but few applied it also to the human mind; thus this world view usually entailed a separation of human mind from Nature. Against the Enlightenment philosophers, others, notably the German Romantics such as Schelling (1775-1854) and Goethe (1749-1832), proposed belief systems that linked humanity with Nature:

Nature was held to be animated by non-mechanical, vital forces, expressing themselves in electricity, magnetism, chemical affinities, in crystal growth, and in

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5 The reader might ask at this point, When can we say we know this? This is an example of the interface between knowledge and belief, an enduring issue in philosophy since Plato, and discussed by the present thesis in the companion chapter on knowledge.
all living things (life). The Romantics were concerned with visible Nature, not with the abstract conception of inert particles governed by mechanical laws. For them, as for Fichte (1762-1814) and Hegel (1770-1831), the Divine was immanent in both Nature and man [sic]. Their task was to heal the breach that had developed between reason and feeling, philosophy and religion, and Nature and man (Naturphilosophie). (Mandelbaum 1983, p. 291)

*The challenge from evolutionary theories*

While the Romantics did not exert a lasting influence, the early mechanistic view of unchanging laws was challenged fundamentally by two developments in the nineteenth and early twentieth centuries. The first was the rise of evolutionary theories, notably those of Charles Darwin (1809-82) and Herbert Spencer (1820-1903). The widespread acceptance of evolutionary theory not only supported the explanation of living things by physical and chemical processes, but clearly identified humanity as part of the cosmos:

The greatest impact of [evolutionary] theory was not its incompatibility with religious orthodoxy, but the clear implication that man [sic], in his origin and his nature, was part of the rest of the organic world. With subsequent applications of the idea of evolution to all phenomena, a new conception of the world as a single, progressive, developmental whole came to be widely shared ... [I]n the late 19th century, and well into the 20th, the idea that all aspects of reality are governed by a law of directional change was widely shared. In contrast to earlier deterministic conceptions of Nature, as operating according to a single set of unchanging laws, the new evolutionary conception of reality held the only unchanging law to be one of development responsible for continuous change. (Mandelbaum 1983, p. 291)

This idea of a single law of development accommodated existing religious beliefs, and in particular the religious derivation of scientific laws which were believed to reflect divinely decreed phenomena. Part of this belief system was the ‘assumption that laws should be viewed as governing and determining events’ (Mandelbaum 1983, p. 291). However, it was difficult to fit all known laws into such a scheme.

*The challenge from positivism and beliefs about laws*

The second development of that period, the rise of positivism, overturned the assumption that laws prescribed or governed events:

When critical positivists, such as Ernst Mach (1838-1916), insisted that laws are simply descriptive, not prescriptive, much of what had been characteristic of both the mechanical and the evolutionary views of Nature was undermined. Laws came to be interpreted as ways of ordering and summarising regularities among observed phenomena, and not as controlling them. (Mandelbaum 1983, p. 291)

That is, laws came to be interpreted as descriptions of regularities, not as prescriptions. The rise of the positivist RV in the twentieth century meant that metaphysical interpretations of the natural world, such as beliefs in fundamental categories were ‘looked upon with suspicion’:

[Philosophers of science have been more inclined to emphasise the structure of scientific explanations rather than to generalise concerning the nature and structure of an independent world. (Mandelbaum 1983, p. 292)]
The impact of the mechanistic view is all the more interesting because in the latter half of the twentieth century the unreserved adoption of one model is contentious: in post-positivist views of science the picture is more complex. Some of these views are extensions of historically enduring viewpoints. For example, Aune (1995) has noted two current but opposing views of Nature. One is a rationalist view ‘that Nature has a structure that can be known a priori’ (Aune 1995, p. 349), that things behave as they do because or their essence or nature:

Aristotle’s conception of the natural world was developed by mediaeval and early rationalist philosophers into the view that nature consists of a system of essences on which God has chosen to bestow existence. This view has adherents even today; they contend that the distinguishing features of individual essences (or ‘possible individuals’) are discoverable from necessary truths to which we have access a priori. (Aune 1995, p. 439)

This view is opposed by an empiricist view, dating from Locke, that we can only know, and therefore classify, natural entities based on their observable properties. In the empiricist belief system, we cannot know essences, nor distinguish objects by them: we can only distinguish and classify objects according to their properties. This is compatible with the view that ‘our decision to adopt a certain convention [of classification] is often affected by our empirical beliefs about the world’ (Aune 1995, p. 350). Yet both these views entail a belief that Nature is made up of objects or things:

In spite of significant differences these earlier views all involve the idea that Nature consists mainly of persisting things (individual substances) spread out in space, interacting with one another, and enduring in time; the persisting things that, at least for non-Aristotelians, are not spread out in space (namely, minds, spirits or intelligences) are intimately associated with bodies that are. (Aune 1995, p. 350)

Some recent ontological beliefs

However, Aune also points out that belief in persisting things, although historically enduring, is not a necessary belief, and indeed is absent from some current views of Nature:

According to most current views, Nature does not contain such things as minds or intelligences; and on some views it is not a system of persisting things but an extremely complex ‘process’ - a system of overlapping events or singularities in a multidimensional ‘field’. (Aune 1995, p. 350)

For example, in recent decades ecological and other post-modern movements have proposed views of Nature that are more holistic than the traditional mechanistic view. Perhaps the best known of these is Lovelock’s Gaia hypothesis, that the Earth, or Nature, be considered as a superorganism, not as the multiple entities studied by traditional, reductionist, science:

The entire surface of the Earth including life is a superorganism and this is what I mean by Gaia. (Lovelock 1995, p. vii)
The Gaia hypothesis is pursued further in section 3 of Chapter 7. Davies and Gribbin (1991) have argued that hypotheses like the Gaia hypothesis may not be inconsistent with world views emerging from other fields of science like quantum mechanics, that is, views that Nature is better thought of as events in fields rather than persisting things:

Far from dominating the activities of the cosmos, matter seems to assume an almost peripheral role. The main activity comes instead from the most insubstantial entities conceivable, a foam of fleeting quantum wormholes, nothing more than a froth of empty space whipped into half-real tunnels, knots and bridges. And it is only by leave of the special properties of this foam that ordinary matter exerts the influence it does in the Universe today; for had the weight of space not been so incredibly close to zero, it would have been quantum vacuum energy, not the gravitation of matter, that determined cosmic dynamics.

... Scientists are increasingly thinking of the physical Universe as less a collection of cogs in a machine, more as an information-processing system. Gone are the clod-like clumps of matter, to be replaced instead by 'bits' of information. This is the shape of the emerging universe paradigm - a complex system in which mind, intelligence and information are more important than the hardware. (Davies & Gribbin 1991, pp. 276-7)

Rapidly emerging and complex developments such as these have been of great metascientific interest. Realists have re-asserted an independent reality determining the possibilities of science knowledge and experiment making sense (see Bhaskar 1983k). Constructivists have emphasised the complex and negotiable character of Nature as studied by science. In the following example, Knorr-Cetina argues that the conventions of using of concepts like Nature are central, which in this respect is more consistent with the conventionalism implied by empiricism than is often recognised:

Constructionism holds reality not to be given but constructed: It sees the whole as assembled ... There are, for constructionism, no initial, undissimulatable 'facts': neither the domination of workers by capitalists, nor scientific objectivity, nor reality itself ...

Constructionist studies disassemble by multiplying - they multiply the players, the events, and the mechanisms associated with sustaining entities such as scientific facts ... Do they also disassemble the material world to which scientific 'findings' refer? Yes, if we mean by this real-world entities represented by scientific descriptions. No, if we mean the existence of a material reality, or the real-time intervention in and causal interaction with this world. Constructionism as exemplified in the first laboratory studies is neither nihilism nor scepticism, nor a doctrine that reduces objects to something like imputed and subjected meanings. Constructionist studies have recognised that the material world offers resistances; that facts are not made by pronouncing them to be facts but by being intricately constructed against the resistances of the natural (and social!) order. What constructionism departed from, however, is the idea that the laws and propositions of science provide literal descriptions of material reality, and hence can be accounted for in terms of this reality, rather than in terms of the mechanisms and processes of construction. Constructionism did not argue the absence of material reality from scientific activities; it just asked that 'reality', or 'nature', be considered as entities continually retranscribed from within scientific and other activities. The focus of interest, for constructionism, is the process of transcription. (Knorr Cetina 1995, pp. 147-9)

Davies (1988, p. 107) acknowledges that 'there is by no means unanimous agreement among physicists, let alone philosophers, either on the nature or existence of reality, or
even its very meaningfulness'; this is clear from the analysis above. What he also notes, however, is that the 'intuitive picture of reality' held by 'most ordinary people' - what philosophers would call naive realism - comprises beliefs that are contrary to those in various fields of contemporary science.
2.6 Nature and magic

Science is characterised sometimes by being distinguished from magic. We are not concerned here with the use of magic to mean clever tricks ‘based upon illusion and deception’, but rather:

... any change with characteristics and results which we do not expect nor usually see in changes. In short, magic is praeternatural\(^6\) rather than supernatural’ (Thomdike 1967, pp. 27-28).

Historically, magical beliefs predate scientific beliefs, and the distinctiveness of the scientific beliefs of the Ionians and other Greeks in antiquity is characterised in some accounts by their differences from these traditional magical beliefs. However, various magical and scientific belief systems remained concurrent alternatives for many centuries and, as we shall discuss, some twentieth century authors remain concerned at the rising public interest in belief systems that the scientific community characterise and reject as superstitions and other beliefs. Recent analyses also point to some inherent difficulties in making clear distinctions between science and magic; the present section will give an account of some of these characterisations and the issues they raise.

There is general agreement that magical belief systems comprise a set of beliefs about the cosmos and the appropriate orientation to it (Thomdike 1923-58; Thomdike 1967; McDougall 1911, 1974; Bernal 1965; Lloyd 1979; Ronan 1982). That is, magical belief systems are characterised by beliefs about, and attitudes towards, the cosmos and how it works:

a legitimate way of expressing a synthesis of the natural world and man’s [sic] relationship to it (Ronan 1982, p. 10)

primitive man’s [sic] … attitude toward nature (Thomdike 1967, p. 29)

a number of beliefs which I believe are all intimately related and which are the marks of a certain attitude towards the world (Thomdike 1967, p. 33).

Note that these statements of early magical belief systems seem to apply equally well to science belief systems. As they stand, they do not distinguish between science and magic. This is significant: recent scholarship has drawn attention to similarities and overlaps between belief systems that are usually characterised as magical or scientific. Keller has argued that it is inherently difficult to distinguish magical beliefs unequivocally:

Magical practices are common to well-nigh all human cultures, but it is seldom easy to distinguish magical techniques from more realistic ones, because in either case the result was the justification. (Keller 1983b, p. 242)

For example, Ronan has argued that beliefs in early cultures had an experiential character that was scientific. An instance is the belief that some phenomena or circumstances will be

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\(^6\) Preternatural: out of the ordinary course of Nature; abnormal (The Macquarie Dictionary)
more beneficial than others, or more disastrous than others: an 'appreciation that man's [sic] survival depends on the behaviour of the natural world' (Ronan 1982, p. 10). This reflects a desire to know the future; interest in prediction also characterises science.

However, beliefs that lucky or unlucky events are behaviours of Nature that result from choices supported beliefs in omens. This marks a difference from typical scientific belief systems. Another subtle but significant difference is that magical and scientific belief systems characteristically share a belief in a connection between the actions of people and the behaviour of the cosmos, but do not share beliefs about the nature of the cosmos and the appropriate orientation to it. An example is the magical belief that people can influence the cosmos, that there is 'an understanding of some connection between man [sic] and the world around him, some primitive comprehension that, given the right procedure, man can control the powers of Nature and set them to work for his own good' (Ronan 1982, p. 10). This belief is consistent with beliefs that underpin the justification of the scientific experiment as a controlled intervention in Nature, and highlights the problems of simplistic characterisations of science and of magic; see the discussion of experiment in Appendix B.5.

Traditional scholarly accounts characterise magic and science as quite different, with magical beliefs being pre-scientific or pre-rational. Recent accounts tend to criticise the assumptions about both magic and science in such distinctions, and the notion that scientific beliefs simply replaced magical beliefs as a sort of linear development. The present section will review some characterisations of magic and science, and critiques of those analyses.

a) Some cautions about characterising differences between science and magic

Characterising magic and science as being clearly distinct presents a variety of problems. First, while many older or traditional accounts made clear distinctions between science and magic, recent analyses have pointed to problems in comparing different belief systems. For example, Appendix B.1 on context discusses post-positivist critiques of the traditional assumption that western European science is the paradigm for rationality (Watson-Verran and Turnbull 1995). Thus it can be easy not to recognise where belief systems are indistinct by closing off further analysis: on the one hand by assuming a priori that 'other' beliefs - mediaeval, ancient European or beliefs from other, traditional, cultures - are simply 'magical' and therefore 'irrational'; on the other hand by assuming a priori the rationality of western European science belief systems and neglecting their analysis. Lloyd (1979) mentions this as a specific issue in characterising beliefs as scientific or as magical, that is found also in other traditional characterisations of science versus non-science, such as primitive versus civilised, pre-logical versus logical, and pre-scientific versus scientific:

First there is the major philosophical issue of understanding alien societies, that is of the commensurability or incommensurability of the modes of thought, beliefs and values of different societies. To translate the concepts of any given society into those of any other is to interpret them, and - so it has been argued - in so doing
inevitably distort them, in particular by prejudging certain key issues relating both
to the nature of truth and to that of rationality. There are, then, some have said, no
culture-independent criteria that can be used as the basis of 'objective' judgments
concerning other societies, and a society can only be understood from 'within',
that is by the actors themselves, not by outside observers. (Lloyd 1979, pp. 1-2)

These problems in appreciating differences, Lloyd continues, clearly apply also to different
groups within the one society; this also is argued in Appendix B.1. Also, it is only the first
of four issues he identifies as affecting analyses of science and magic.

The second issue affecting analyses of science and magic arises in anthropology. It
relates specifically to studies of what is loosely characterised as magic, and that is 'a
critique of the old idea which saw magic as, broadly speaking, failed applied science'
(Lloyd 1979, p. 2). Thus the earlier analyses are often regarded as interpretively dated
because they use what are now regarded as simplistic notions of mystical, common-sense
and scientific. An example of the more recent approach is Cavendish (1977):

Magic is an attempt to exert power through actions which are believed to have a
direct and automatic influence on man [sic], Nature and the divine. It is impossible
to isolate the history of magic completely from the history of religion or science.
The religious, scientific and magical attitudes to experience are distinct from each
other in theory. The religious impulse is to worship, the scientific to explain, the
magical to dominate and command. But in real life attitudes are not kept in separate
compartments and the distinctions are frequently blurred. In the distant past
everything strange was magical, or religio-magical, and this was true of humans as
well as the environment. (Cavendish 1977, pp. 1-2)

Lloyd argues that such distinctions are simplistic because they rest on narrow
caracterisations, such as observational data being the simple and sole criterion of science
and objectivity:

Any attempt to contrast magic as a whole directly with science is now seen to be
liable to distort the nature and aims of the former. Magic, so it has been forcefully
and in part, at least, surely rightly argued, should be seen less as attempting to be
efficacious, than as affective, expressive or symbolic. The criteria that are relevant
to judging magical behaviour are not whether it achieves practical results but
whether it has been carried out appropriately or not. (Lloyd 1979, p. 2)

For Lloyd, the trend in anthropological analyses of belief systems is towards more
ethnographic inquiries, that describe how the people who practiced those beliefs interpreted
them. Thus there has been a move away from labels such as mystical and pre-scientific,
towards descriptions; the criteria for judgment accordingly shifts from whether particular
beliefs are effective, towards how skilfully the beliefs are used. The present thesis extends
Lloyd's critique, to argue that a multi-dimensional characterisation of science, and indeed of
magic, identifies a more complex interplay of characteristics that clarifies the similarities and
differences.

The third issue raised by Lloyd arises in post-positivist metascience, that generally
recognises the role of consensus in forming scientific beliefs:

[T]he effect of [Kuhn's] work has certainly been to draw attention to the role of
the consensus in the scientific group and to that of their shared implicit
assumptions, and this in turn has made it easier to see the important similarities between the scientific, and other, communities, and between science itself and other belief-systems. (Lloyd 1979, pp. 3-4; emphasis added)

Thus there has been a shift not only in anthropological interpretation but in metascience, that is, our views of the nature of science.

The fourth issue Lloyd sees as affecting analysis of the relationship between science and magic arises from developments in studies of linguistics and the technology of communication. These analyses also question traditional dichotomies such as primitive versus advanced, but from the view of the linguistic and other cultural resources available to various cultures. In this view, the traditional characterisation of so-called pre-scientific societies as those unable to reflect, should be reinterpreted as traditional societies not having the appropriate linguistic tools for ‘constructive rumination’ (Lloyd 1979, p. 4).

Lloyd does not advocate a complete relativism, merely that recent research in several fields has been more conscious of identifying assumptions. For example, ‘it is also agreed on all sides’ both that myth and magic were important in antiquity, and that ‘inquiries that are recognisable as science and philosophy were developed in the ancient world’ (Lloyd 1979, p. 5). There is also agreement that in Europe there was ‘some kind of developmental sequence’ (p. 5) in which scientific practices and beliefs emerged from early, magical beliefs, but this should not be taken to mean that a scientific set of beliefs simply replaced earlier magical belief systems, because a number of belief systems remained in use over a thousand years, nor that this sequence should be taken as applicable to other, non-western European cultures.

b) Characterising magical beliefs systems in antiquity and mediaeval times

Traditional histories identify a range of belief systems and practices under the label magic:

Magic was (and continues to be) a system of beliefs underpinning a body of technical or craft knowledge and practice, which sought to capture and control the powers and processes of Nature for man’s [sic] (or perhaps merely the individual adept’s) advantage. Such magical traditions appeared in the earliest civilisations and manifested themselves in a number of different but related arts and sciences. There are major divisions, such as those between Spiritual, Demonic and Natural Magic, or astrology and alchemy, and innumerable smaller divisions between different sorts of divination - palmistry, scrying, sortilege, harilolation and many more. These different forms of magic had their own techniques and procedures and their own specific justifications but they were all founded upon a particular view of the world. (Henry 1990, pp. 583-4)

Keller (1983b) has characterised varieties of magic as two broad, overlapping classes of magical practice that embody two notions of cause and effect: sympathetic magic, representing a belief that phenomena are caused by the attraction of likes or repulsion of opposites; and spirit magic, representing a belief that natural phenomena can be countered by the greater powers of spirits, souls and demons. The purpose of both was to control Nature: the former by expert knowledge of affinities and antipathies; the latter by the secret
knowledge of enlisting or controlling the power of spirits. We will examine both of these as examples of beliefs that are central to widespread belief systems, used typically as contrasts with scientific beliefs.

Spirit magic

There was widespread belief across many early cultures in souls or spirits as the animating principle of living organisms. McDougall (1911) has argued that this was not equivalent to the modern conception of the human soul, which has been developed over centuries of philosophical and theological debate. In early belief systems, souls or spirits had an almost parallel existence to the physical body. They were partly material, in that they had a similar form, had similar needs and experienced similar emotions to the body. At the same time they were partly immaterial, in that they were usually invisible, or appeared only as apparitions, and were less dependent of the normal physical constraints of time and space. McDougall argued that support for this belief came from the experience of sleep and dreams. The appearance of dead relatives and friends in dreams was believed to be the appearance of their spirits or souls after the deaths of their material bodies. The first-hand experience of strange adventures and visiting other places in one’s own dream was similarly believed to be the experiences of one’s own spirit while separate from the body:

Sleep is regarded as due to its temporary withdrawal from the body; trance, coma, and other serious illness, as due to longer absence; and death is thought to imply its final departure to some distant place. (McDougall 1911, p. 1)

Similarly, the ghost-soul was believed to concern breath, where air passes in and out of the body during life but not in death, and the shadow, which bears a likeness to the active person but disappears when lying down in sleep or death (McDougall 1911, p. 3; Ronan 1982, p. 70). Thus the soul or spirit was believed to be the animating principle that gave life to the body, and capable of separate existence during life and continued existence after the death of the body.

Elements of animistic views of the cosmos are found in examples from many cultures, as mentioned in section 2.12 below. Other beliefs are given in the literature as also characterising the differences between the Western European scientific tradition and other traditions of thought. Jaki’s (1974) detailed analysis of cosmological beliefs in various cultures points to a number of features which he claims mitigated against the formation of a scientific tradition as it did in western Europe. While interpretatively contentious - Jaki makes historical and cultural judgements from the perspective of twentieth century western Europe - his analysis provides many examples of differences in beliefs. Central among these are beliefs that the cosmos is cyclic and attendant beliefs to this cyclic nature, including various accounts of and attitudes towards causality. Second is the omnipotence of deities that discourages human inquiry into the cosmos. Third is the effect of the concepts
available for describing and discussing the cosmos. These are discussed in section 2.12 below.

**Sympathetic magic**

There were other beliefs about cause and effect, such as a belief that one part of Nature, such as rain, can affect another part, such as crop growth:

an essentially imitative and sympathetic kind of theory of the working of the universe. (Bernal 1965, p. 87)

Ronan (1982, p. 10) described this as a notion of natural cause and effect, not simply of unrelated phenomena, and not of some other relationship between phenomena: that the phenomenon of rain causes the phenomenon of crop growth. Using examples like this, Ronan argued that many very early beliefs about the cosmos have a recognisably scientific character. We have noted Lloyd's caution that recent anthropological approaches have identified skill or efficacy as the goal of some traditional magical practices, not control. However, as we have also seen, Keller identified influence or control over Nature as the goal of two main magical belief systems, spirit and sympathetic magic. The present thesis, in the companion chapter on purpose and Appendix B.3, identifies control over Nature as a characteristic goal of science; clearly, this goal alone is insufficient to make a distinction between science and magic without accounting for the belief systems.

Implicit in beliefs of sympathy and affinity are related beliefs about the appropriate orientation to the cosmos. That is, characterisations of science versus magic often refer to beliefs about appropriate activities and goals: beliefs about how humans are able to influence Nature in this way. This is a point of distinction in some accounts:

To make life go as he [sic] wished, he must be able to please and propitiate or to coerce these forces outside himself. In this endeavour his faculty of association probably led him to conclude that things resembling each other or having any seeming connection must be related by strong bonds or sympathy and have power over each other. Since he had already attributed human characteristics to [non-human] matter, he naturally now observed no distinction between the animate and the inanimate, the material and the spiritual. A wooden image might be used to affect the fate of a human being, or the utterance of alluring and terrifying sounds to produce change in unfeeling and unresponsive matter. (Thorndike 1967, pp. 29-30)

The connection between the body and its spirit was made typically with artefacts of the body: clippings of hair or nails are common examples. The connection is more than simply historical or symbolic; there is believed to be an affinity or sympathy between the two. The notion of affinities and sympathies leads a system of beliefs about sympathetic magic, which is either contagious (requiring physical contact between the two things which have an affinity) or imitative magic (in which the two do not have to touch but be in proximity). Thus another person could be influenced by means of a doll or effigy which featured a clipping of hair or some other artefact from that person. The performing of a rain dance by the witch-doctor or shaman was similarly imitative. It also led to systems of totemic
organisation, in which tribes or other groups identified themselves with whatever animal, plant, hero or other whose features or qualities were sought for the group.

Ronan has argued that this system of beliefs about the cosmos entails a particular orientation to the material world that was not an investigative or inquisitive attitude:

... Magic gave expression to what was, by and large, an animistic view of Nature. The world was populated with and controlled by spirits and hidden spirit forces, residing perhaps in animals, or trees, or in the sea and wind, and the magician's task was to bend these forces to his [sic] purpose, to make the spirits co-operate. He made invocations, cast spells and prepared potions, because he saw a world of affinities and sympathies. This outlook might lead to sympathetic or imitative magic, where men might eat the flesh of an animal in order to absorb some of its qualities, or dress up like the animals and enact their capture and death so that their hunt might be blessed with success. Drawing or painting pictures of animals or making figurines of them extracted power from them, so weakening them and helping their capture. The magical world was a world of relationships rather than independent objects, and was based on man's own interrelations with the life and conditions he found around him in a world where forces were personified and everything had a specific influence. (Ronan 1982, p. 11)

The microcosm/macrocosm analogy

Beliefs that the cosmos has human characteristics are known in anthropomorphic myths from antiquity, in the early natural philosophies of China, India and Persia, and in the writings of many of the early Greeks, including Plato and Aristotle. They may be summarised as belief that the human form is a microcosm of the macrocosm of the universe - that the form of humans is analogous to the form of the cosmos, and vice versa. For Thorndike (1967, p. 29) it is a 'safe assumption' that there would have been no reason to suppose the surrounding environment was any different from the human observer. Thus the cosmos was believed to be ensouled, and subject to the same emotions, foibles and goals as people: capricious, capable of responding in wrath, capable of being persuaded by bribes, gifts or threats, and so on. Although this belief did not greatly concern Aristotle or many of the early Greek medical and astronomical writers it remained popular with idealist philosophers, and others, down to the Scientific Revolution in the seventeenth century. The belief that spirits reside in all things in Nature is animism (Bynum 1983). All aspects in Nature were believed to possess this animating principle, including other animals, plants and inorganic objects that today are believed to be inanimate, or animate but lacking consciousness. This belief, and the microcosm/macrocosm analogy, were part of a belief system that supported magical beliefs in correspondences and sympathies. Thus many writers in antiquity and the Middle Ages sought to identify numerological correspondences between the human form and the cosmos, that is, number mysticism; similarly the alchemists sought correspondences, or sympathies, and antipathies between human and inorganic chemicals. These beliefs were supported by Aristotle's notion of occult virtues, which could not be directly observed.
Interestingly, Keller (1983c) has argued that the microcosm/macrocosm analogy has some similarities with recent views of the Universe as an evolving organism, but this belief is not part of a belief system that includes correspondences and souls.

c) The influence of the mechanical belief system

The mechanistic belief system that emerged in the Scientific Revolution opposed all these beliefs at once: the microcosm/macrocosm analogy and belief in correspondences, the belief in souls, spirits and demons, and beliefs about the appropriate way to gain knowledge of that universe:

Predicting the future changed into a scientific instead of a religious, magical or psychic exercise. (Cavendish 1977, p. 122)

The emerging view of Nature in the Scientific Revolution entailed a rejection of beliefs that the cosmos is organic and ensouled, and with them the decline of magical views of Nature (Bronowski 1978; Easlea 1980). Bronowski has characterised science as an interpretation of Nature (see summary statements 16, 73, 74) that is distinguished from magical world views by beliefs that arose during the fifteenth to seventeenth centuries. On his account science is a unified way of looking at the world, or a world view, which in the light of the preceding discussion we would term a belief system. This belief system is distinguished from earlier unitary views of the world by acknowledging only one form of truth or logic. Humanity is assumed to be part of Nature and subject to the same rules of investigation and rationality. This, on Bronowski’s account, is the central difference between the scientific belief system(s) that emerged at this time and the magical belief systems it began to replace. One cannot do science by magic, nor does science apply to only one part of the cosmos. This standpoint entails a belief that the nature of the cosmos is uniform or consistent, such it can be investigated scientifically and not magically:

The form of magic that I shall discuss is the notion that there is a way of having power over nature which simply depends on hitting the right key. If you say 'open sesame' then nature will open for you; if you are an expert then nature will open for you; if you are a specialist of some kind or if you are remote, if you are esoteric, if you are an initiate there is some way of getting into nature which is not accessible to other people.

Now this was the dominant theme of all those centuries up to the fifteenth. And all primitive forms of magic - sympathetic magic, the kind of magic you read about in Levi Strauss for instance, magic that structuralists talk about - all come back to this notion: there is a way of having power which is esoteric and does not depend on generally accessible knowledge. Now I think that is fundamentally dangerous, because it recurs in every generation ...

(Bronowski 1978, p. 20)

This passage is especially interesting because, again, it does not in itself make a clear distinction between science and magic, despite Bronowski’s evident belief that they are quite distinct. It therefore emphasises how difficult it is to support traditional boundary work in establishing such a distinction. More information is needed.
Bronowski describes a shift in thinking around 1500 to 1550, concerning how this magic could work. He draws attention to the power of memory and imagination, especially in people of great faith or belief. He acknowledges the power of persuasion from one person to the next - seemingly a spell - but then develops this to a consideration of whether the persuasion or spell could work on dead or inanimate matter. He then describes a shift in beliefs about the conditions under which such a spell could work:

In black magic, the belief was that you would make nature run against her [sic] will. In white magic, you began to say, 'Well you know, let's make nature work with us. There is a harmony; we could exploit it.' Finally came the concept of natural law itself. And that was represented, in a most spectacular way, for the first time in the writing of Francis Bacon between 1600 and 1620. It was Francis Bacon ... who was the first person to say 'knowledge is power.' It was Francis Bacon who said in the *Novum Organum* 'we cannot command nature except by obeying her.' At this point, the scientific revolution was really complete. (Bronowski 1978, p. 33)

These shifts represent shifts in ontological beliefs, from a belief that the cosmos can respond to esoteric commands and incantations, to a belief that the workings of the cosmos can be distorted if not commanded, to a belief that the workings of the cosmos can be neither commanded nor distorted. This is when people dared to break magical taboos and realised there was no magic. Bronowski quotes Pompanazzi (1462-1525) as providing in his book *Of Incantations* a clear statement indicating this shift in beliefs:

It is possible to justify any experience by natural causes and natural causes only. There is no reason that could ever compel us to make any perception depend on demonic powers. There is no point in introducing supernatural agents. It is ridiculous as well as frivolous to abandon the evidence of natural reason and to search for things that are neither probable nor rational. (Bronowski 1978, p. 33)

It is true that magical beliefs died harder in the general populace than in scientific writings and practice, but the demise of magical beliefs in this context is clear:

(Any) ideas which required non-mechanical action without contact began to look more implausible as the 17th century drew on. Although some scientists maintained a belief in the possibility of demonic witchcraft, that too declined rapidly after c1660, for the new science seemed utterly hostile to immaterial forces and animistic powers. By the 18th century, not only was the Renaissance natural magician gone, but spirit magic had descended into cozening and conjuring tricks. (Keller 1983b, p. 243)

d) Contemporary issues

It is also true that superstitions and logics of argument, similar to the arguments for magic we have discussed, remain today. For these reasons Bronowski extends the implications of his belief that the cosmos is explained by a single, uniform logic: (1) a scientific view precludes a magical view, and (2) saying that something is so doesn't make it so. For Bronowski these beliefs make a claim on the logic of argument in everyday life:

My definition of magic is (simply) the view that there is a logic of everyday life, but there is also a logic of another world. And that other logic works in a different
way and if you can only find the secret key, if you can enter into some magical practice - particularly if you can find the right form of worlds - then either the Almighty will be on your side, or you will collect the votes, or people will believe that because you call it peace, that it's not the same word as war, and all those other things which Orwell has portrayed so brilliantly but which really always come up to the same thing: trying to command the world and particularly the opinions of other people by some formula which is other than the truth. (Bronowski 1978, pp. 11-12)

This claim has obvious implications for the place of science more widely in contemporary society and therefore for the place of science in the general education of the populace, the subject of the present thesis. But it provides food for thought even as an internalist statement. For example, quantum theory provides some difficulties with the simultaneous interpretation of sub-atomic and macro phenomena (Madden 1983; Wheaton 1983). The present thesis suggests that this arises because of two different belief systems that are not easily reconciled, at least by those without a current working knowledge of quantum theory. At this level quantum theory could be considered as entailing a magical belief system as Bronowski describes. However the present thesis argues that this difficulty lies in Bronowski's characterisation, which is inadequate. Instead, one has to consider the complete belief system, not merely some elements of it, and in combination with other dimensions of science. Thus magical beliefs are typically characterised as entailing preternatural and/or supernatural beliefs, which are just as typically excluded from scientific belief systems. Further, scientific beliefs are linked to broader intellectual (internalist) contexts, peer (external) review, experimental test (activity), and so forth.

This sort of argument has been put by many commentators, but the following is a strident example, from the physicist Ian Johnston on the Science Show, a radio program of the Australian Broadcasting Corporation:

The strongholds of science are under siege. Beyond the ramparts of rationality there sits encamped a vast army of ratbags, all scuttling like orcs about their weird machines, cranking up their theories, whipping up their disciples and railing against the despised establishment. Against this horde ordinary rational men and women can at best engage in guerrilla warfare - cut off a few stragglers, harass the occasional rearguard and snipe from cover. For though some battles might be won, the war is never-ending.

Ratbaggery seems to be on the increase. The Australian writer Christopher Koch, in a recent interview about his latest novel The Dutchman which is peripherally concerned with occult practices, said he believed that we are more superstitious today than at any time since the 14th century. I don't know if he has any figures to back this up but I, for one, am inclined to agree with him. While new bits of ratbaggery are continually appearing, none of the old ones ever seem to die out. As time goes on, there are simply more and more of them. (Johnston 1986, p. 34)

In this classic piece of boundary work, Johnston lists some of these 'ratbaggeries', in which he includes a rise in fundamentalism (presumably both religious and political), eastern mysticism, new religions, articles on astrology and numerology that are commonplace in the popular press, UFOs and extraordinary medical claims by folk with no
medical training and whose claims they will not subject to external scrutiny. In his introduction to Johnston’s article, the editor Robin Williams observed that Johnston’s broadcast resulted in a flood of correspondence protesting that science is fallible, but that this misses the point:

Besides, [Dr Johnston] is not claiming that science holds all the answers, only that there are too many scoundrels trying to dupe us and that they may get away with it much more in the present climate of uncertainty and depression. (Williams 1986, p. 2)

A constructivist approach to boundary work suggests that delineating science from ‘ratbaggery’ is difficult and will vary depending on whose views are considered. For the moment, Johnston’s argument reminds us that belief systems (at least among other dimensions) remain in use in current times by those wishing to characterise science and distinguish it from non-science. The present thesis suggest that clarifying the respective belief systems, together with their interdependent contexts, knowledges, purposes and so forth, is a means of scrutinising such claims.
2.7 Nature and God

Roughly parallel to the shift in belief that Nature is organismic to a mechanised Nature, were changes in beliefs about the relationship between God and Nature. An organism can have its own intelligence, but a mechanism implies a creator and, for some, a controller. Such changes in fundamental ontological beliefs therefore led to clashes, which in the history of western European science were usually with the established Christian church in Europe. The clashes between Church authorities and Copernicus and Galileo, for example, are widely known in science history. Conflicts such as these can be represented as conflicts between belief systems and also as challenges to power and authority. To cast the slow emergence of classical science merely as a conflict between belief systems concerning Nature, one being based on theological principles and another based on observation, is to miss the subtlety and complexity of what was clearly a significant philosophical debate.

Scholasticism in both senses of the word was not the only confounding factor in the re-emergence of Aristotelian teaching in Europe. Nor would it be correct to characterise Aristotelian science of this time as being based on observation. Some of the complexity of the debate is accounted for by a reconciliation of what Dijksterhuis (1986, p. 129) called 'the religious and the intellectual world-conception, of faith and science'. This reconciliation of views was due largely to the English Franciscan Alexander of Hales, the German Dominican Albert von Bollstädt (later known more commonly as Albertus Magnus), and in particular the Italian Dominican Thomas Aquinus (later to be St Thomas). In this synthesis, the Aristotelian belief system became accepted in the thirteenth century as the philosophical counterpart to accepted Christian beliefs. This was despite conflict with Christian beliefs from such Aristotelian claims that the Earth had existed from eternity and would exist into future eternity. In brief, a 'synthesis' was achieved by urging Christians to study Nature even more carefully:

Therefore in complete contrast with the dominant patristic view, Thomas in the opening pages of the second book of the *Summa contra Gentiles* urges the necessity of studying science: it supports religious instruction and helps to eradicate errors. The works of God reveal His wisdom and power. Studying created things will therefore intensify man's [sic] love of God. (Dijksterhuis 1986, p. 131)

In opposition to the bookish tradition which had come to dominate medieval science in Europe, this was to be done by studying Nature rather than what previous scholars had said about Nature. In contrast to the view accepted in the Middle Ages, science was not lost,

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7 See the companion chapter on context and Appendix B.1.
8 The 'Thomistic synthesis'; see Dijksterhuis 1986, pp. 128-135.
awaiting rediscovery. Nor, however, was all knowledge already present; it grew with the contributions, including mistakes, of those who studied Nature.

Thus by the seventeenth century there were several centuries of philosophical and institutional ties between what had been antithetical belief systems:

Seventeenth century natural philosophers inherited two different concepts of God's relation with His Universe: (a) as supremely wise, God had constructed an orderly and rational world displaying evidence of design; (b) as supremely powerful, God was able to disrupt this order miraculously and was the source of activity in the world. (Schaffer 1983, p. 169)

These two beliefs concerning the relationship of God to Nature elicited various responses at that time of intellectual ferment and in the scientific tradition that followed down to the present (Schaffer 1983; Dijksterhuis 1986; Oldroyd 1989). Some historical examples of beliefs about God's relation to the universe are given in Appendix B.1.

The relation of God to Nature, and hence also the relation of God to science, continues to be debated down to the present. Both in philosophical circles and among the general community, it has remained a contentious dispute that concerns fundamental beliefs about Nature, God and science:

Four hundred years ago science came into conflict with religion because it seemed to threaten Mankind's [sic] cosy place within a purpose-built cosmos designed by God. The revolution begun by Copernicus and finished by Darwin had the effect of marginalising, even trivialising, human beings. People were no longer cast at the centre of the great scheme, but were relegated to an incidental and seemingly pointless role in an indifferent cosmic drama, like unscripted extras that have accidentally stumbled onto a vast movie set. The existentialist ethos - that there is no significance in human life beyond what humans themselves invest in it - has become the leitmotif of science. It is for this reason that ordinary people see science as threatening and debasing: it has alienated them from the universe in which they live. (Davies 1992, pp. 20-1)

It is highly significant that these conflicts are characterised less by particular knowledge claims or activities, the traditional categories of characterisation, than by fundamental concerns with belief systems.

There are several examples that show that science continues to be characterised partly by beliefs about Nature and God. The theoretical physicist Stephen Hawking reported attending a conference, hosted by the Vatican, on cosmology and involving the respective roles and claims to truth of religious and scientific beliefs (Hawking 1988, p. 122). Another physicist, Paul Davies, is one of several scientists who has written recently about these respective roles, and what he characterises as shift in the traditional boundaries between the two:

In later years I began doing research on topics like the origin of the universe, the nature of time, and the unification of the laws of physics, and I found myself trespassing on territory that for centuries had been the near-exclusive province of religion. Yet here was science either providing answers to what had been left as dark mysteries, or else discovering that the very concepts from which those mysteries drew their power were actually meaningless or even wrong. My book
God and the New Physics was a first attempt to grapple with this clash of ideologies. The Mind of God is a more considered attempt.

Since publication of the first book, a lot of new ideas have emerged at the forefront of fundamental physics: the superstring theory and other approaches to so-called Theories of Everything, quantum cosmology as a means of explaining how the universe might appear from nothing, Stephen Hawking’s work on ‘imaginary time’ and the cosmological initial conditions, chaos theory and the concept of self-organising systems, and advances in the theory of computation and complexity. In addition, there has been an enormous resurgence of interest in what might be crudely described as the science-religion interface. This has taken two distinct forms. First, a greatly increased dialogue between scientists, philosophers, and theologians about the concept of creation and related issues. Second, a growing fashion for mystical thinking and eastern philosophy, which some commentators have claimed makes deep and meaningful contact with fundamental physics. (Davies 1992, pp. 13-14)

Thus Davies characterises science, or at least physics, as appearing now to address questions that have traditionally been the subject of religious beliefs, not science beliefs: in particular, he notes scientific speculation about the origin of the Universe. We could include also developments in cloning mammals that unfold as this thesis is being written.

There are several approaches to this ‘science-religion interface’. Davies points to two among practicing scientists who are also religious. Some appear unconcerned about disharmony of belief: those who practice conventional religion seem to keep the two belief systems separate, ‘as if science rules six days a week, and religion on Sunday’ (Davies 1992, p. 15). Others, who attempt some harmony between their beliefs, seem to adopt relatively liberal views of religion while ‘imbuing the world of physical phenomena with a significance that many of their fellow scientists find unappealing’ (p. 15). Davies’ own conclusion fits in the second camp: his argument is that the nature of the cosmos entails thinking beings who can speculate and inquire about the cosmos, even though our very rules of reasoning probably preclude us from ultimate knowledge of it. Davies remains open-minded about the possibility that mystical experiences may be perhaps the only means of gaining such knowledge, but he speculates that the self-awareness of humans who can inquire scientifically is not accidental:

The central theme that I have explored in this book is that, through science, we human beings are able to grasp at least some of nature’s secrets. We have cracked part of the cosmic code. Why this should be, just why Homo sapiens should carry the spark of rationality that provides the key to the universe, is a deep enigma. We, who are the children of the universe - animated stardust - can nevertheless reflect on the nature of that same universe, even to the extent of glimpsing the rules on which it runs. How we have become linked into this cosmic dimension is a mystery. Yet the linkage cannot be denied.

What does it mean? What is Man [sic] that we might be party to such privilege? I cannot believe that our existence in this universe is a mere quirk of fate, an accident of history, an incidental blip in the great cosmic drama. Our involvement is too intimate. The physical species Homo may count for nothing, but the existence of mind in some organism on some planet in the universe is surely a fact of fundamental significance. Through conscious beings the universe has generated self-awareness. This can be no trivial detail, no minor by-product of mindless, purposeless forces. We are truly meant to be here. (Davies 1992, p. 232)
As it does with claims by other others, the present thesis argues that Davies' claim that we have cracked part of the cosmic code is a statement of belief: that Davies is really expressing a belief system rather than an immutable truth. After all, the history of science is replete with eminent and astounding thinkers whose statements have later been modified or rejected. However, that is not the significant point here. The significant point is that Davies' argument characterises science partly by beliefs: that we human beings are able to grasp at least some of Nature's secrets, and, because he cannot believe that human rationality is accidental, by implication Davies believes that is 'meant to be'.

Beliefs that science and religion can co-exist

There are other approaches to the 'science-religion interface' that also demonstrate that science continues to be characterised partly by beliefs about Nature and God. In discussing scientists who also hold religious beliefs, Davies focussed on the matter of reconciling scientific and religious beliefs. Variations of this approach have been advocated by other scientists (Hanbury Brown 1986; Falconer 1987). Usually, they emphasise a need to dissociate religious beliefs from scientific beliefs about Nature:

Nevertheless there will always be people who insist that the doctrines of Christianity must be supported by supernatural authority, and that it is the existence of an authority external to nature which is the basic difference between religion and humanism. In that case the important point, as far as the relations between science and religion are concerned, is that any concept of the supernatural which is used should not involve, in any way whatever, the contra-natural. (Hanbury Brown 1986, p. 178)

That is, Hanbury Brown accepts that it is reasonable for an individual to have both religious and scientific belief systems, but they will be mutually incompatible if the religious beliefs entail a belief that Nature can be made to act counter to its usual behaviour (contra-natural). This contra-natural behaviour is a different sense to manipulating phenomena in experimental conditions, which is a test for knowledge in science. This is put succinctly by Archer:

A crisis looms. While scientists have become rapt in the utterly fascinating business of exploring the nature of the universe, of which the evolutionary process is a part, they have as a group failed in the important responsibility of adequately communicating this understanding to the general community. A consequence of this failure has been the rapid growth of a vocal minority who incorrectly perceive an inevitable consequence of scientific inquiry to be the discovery that there is no God. They fear that the study of evolution will reveal a God-less origin of, and God-less purpose for, life.

Two vitally different matters are being confused here. The business of science is to observe, explore and understand every possible aspect of the material universe without regard to the existence or otherwise of super-natural phenomena. It cannot be the business of science to pass judgement on the existence of spiritual phenomena because it is impossible to subject such matters to scientific analysis (Wielert 1983). (Archer 1987, p. 14)
Archer's is a clearer characterisation of science than Johnston or Davies, above, although it is still an instance of boundary work. Also, it is a pertinent analysis of the opposition of a mainstream scientific belief system and certain religious belief systems in western (and some non-western) cultures.

Beliefs that religious beliefs take precedence over scientific beliefs

Beliefs such as those expressed by Archer and Hanbury Brown are directly opposed by some groups, typically outside the scientific community, who argue that religious belief ultimately over-rides scientific belief. Nelkin (1995) has argued that this view has been especially strong in the USA, whose individualistic culture has fostered a rhetoric of citizens' rights. This includes the rights of citizens, as advocated by these groups, to choose religious beliefs that conflict with science beliefs:

Studies of controversies suggest their origins in a range of political, economic, and ethical concerns (Engelhardt & Caplan 1987; Graham 1979; National Academy of Sciences, Institute of Medicine 1991). First, the most intense and intractable disputes concern the social, moral, or religious implications of a scientific theory or research practice. The controversy over the teaching of evolution in public schools has persisted at the level of local [US.] school districts, even after a US. Supreme Court decision seemed to bring closure to the issue (Nelkin 1984) ... Creationists see the teaching of evolution as a threat to their right to maintain the religious faith of their children. (Nelkin 1995, pp. 447-9)

Thus for Nelkin, the science-religion interface needs to be interpreted as part of the wider issue of public controversies concerning science that includes animal rights, control of reproductive technologies and pollution. The example of Creationism in the science curriculum is discussed further in the final chapter of the present thesis, as an example of a significant science curriculum issue that can be informed by the present thesis.

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9 In this passage, Archer characterises science not just by belief system (… of the material universe without regard to … super-natural phenomena) but by purpose (the business of science is to …) and activity (subject … to scientific analysis).
2.8 Nature and mathematics

The tradition of western European science, especially from the Scientific Revolution, is characterised partly by a significant role for mathematics (see, for example, Taton 1975). This entails beliefs about the mathematical nature of the cosmos that have persisted down to the present:

Science is predicated upon the belief that the Universe is algorithmically compressible and the modern search for a Theory of Everything is the ultimate expression of that belief, a belief that there is an abbreviated representation of the logic behind the Universe's properties that can be written down in finite form by human beings. (Davies, in summary statement 85)

Developments in mathematics were made concurrently, and often interdependently, with other developments in science. That is, the beliefs associated with the developments in mathematics arose interdependently with other beliefs and were included in the development of scientific belief system(s), notably the rise of the corpuscular view of the cosmos. The increasing use of mathematics in describing and analysing natural phenomena presupposes decisions about what entities in the cosmos - what metaphysical qualities - can be quantified, what can be ignored, and so forth. Some details of developments in mathematics are given in Appendix B.5; the present section will simply argue that mathematics has historically played a role in forming and clarifying science belief systems.

Histories that emphasise the continuity of beliefs point to the use of mathematics in natural philosophy from antiquity. We have noted the use of mathematics by Thales, and that the works of Plato and Aristotle represented two different approaches to the use of mathematics in constructing a world view. That is, they proposed two different belief systems concerning the place of mathematics in ontological and epistemological beliefs. Dijksterhuis (1986) has traced mathematical developments in the Western European scientific tradition from the ancients through to Newton and, by implication, down to the present.

Histories that emphasise discontinuity of beliefs point to the significance of the changes labelled the Scientific Revolution, in this case the fundamental changes in the mathematical character of science (see Needham in summary statement 72 and Davies in summary statement 86). In particular these changes are characterised as the re-emergence of the belief (following Plato's teachings) that the cosmos could be described mathematically; this provided the basis for a flourishing of mathematical scientific activity. For example, graphical representation, introduced by Oresme, enabled the more sophisticated conceptions of variability to be developed that are so important in conceptualising motion, among other things. Newton and Leibniz developed the mathematics of infinitesimals which, through differentiation and integration, became a useful and widely used tool for analysing physical change. The increasingly clearer and quantifiable concepts of force, motion and change
contributed to the reassessment of ontological beliefs, particularly the long-held belief in the perfection of circles and spheres, and that the structure of the cosmos shows spherical and circular forms (Dijksterhuis 1986, p. 263).

The work of Galileo Galilei (1564-1642) showed a combination of elements from both Aristotle and Plato. At the time of Galileo, orthodox physics was Aristotelian and astronomy was Ptolemaic. That is, the physical cosmology was Aristotelian although the Aristotelian experimentation had largely been replaced by scholastic interpretation of Aristotelian texts (Singer 1959, pp. 55-56), as mentioned above. Also, the Aristotelian-Islamic cosmology had been fused with theological doctrines of the Roman Catholic church, in the Scholasticism following Thomas Aquinas. Galileo revived the experimental basis of Aristotle, but proposed a cosmology that was both different to that of Aristotle’s and (as with Plato) capable of being represented mathematically:

In Aristotle’s physics, motion was regarded as a quality: a body would be moving or stationary according to whether it possessed the quality of motion. But it was not possible to treat such an Aristotelian property satisfactorily in terms of numbers, and hence examine the phenomena of motion in more than a general manner. By contrast, Galileo’s falling bodies were, so to speak, ‘mathematical’ entities, moving in ‘mathematical’ space. All their attributes (such as colour, smell, weight, etc) were disregarded (for the purpose of the experiment on falling bodies), and attention was focussed solely on position and time. So in a sense Galileo was no longer dealing with real bodies moving in real space, but with ‘mathematical fictions’. (Oldroyd 1989, p. 58)

Thus Oldroyd characterises Galileo as drawing on both Aristotle and Plato, but not wholly following either tradition. Galileo sought mathematical representations of the cosmos, unlike ‘the generalisations of everyday experience that characterised the physics of Aristotle’ (Oldroyd 1989, p. 53). However, unlike a strict neo-Platonist, he represented the cosmos using mathematical models and experiment.

More important than any of the individual changes in beliefs was that they fitted together as a coherent set or system of beliefs: a plausible and useful synthesis of ontological, epistemological and methodological beliefs. These include notions of experimentation, the use of mathematics, as described above, and the relation of this mathematics to metaphysical entities, as will be shown below. For example, John Heilbron makes such a distinction between Galileo and his Mediaeval predecessors in terms of these beliefs:

But these anticipators [such as Nicole Oresme (c1320-1382) and Domingo de Soto (c1494-1560)] do not appear to have shared Galileo’s approach: they investigated laws of motion as mathematical possibilities, he as testable descriptions of Nature. (Heilbron 1983b, p. 229)

So these mathematical developments are not simply technical or methodological advancements, but shifts in beliefs as to what the mathematics represents: new ontological and epistemological possibilities. It is the ontological and epistemological implications that are most significant:
A particular importance attaches to the revival of interest in Plato’s philosophy and the metaphysics of mathematics as the key to truth which powerfully affected (in different ways) both Galileo and Kepler. The introduction in the late 16th and early 17th centuries of mathematical theories applicable to actual natural events (such as the fall of heavy bodies) - as distinct from mathematical models ‘saving the phenomena’, as in astronomy - was the greatest innovation in theory-construction since Aristotle. (Hall 1983, p. 379)

The best-known example of saving the phenomena is no doubt the preface to the posthumous publication of Copernicus’s *De Revolutionibus*. It is thought that this was added by Osiander to ‘save the appearances’. This line of thinking argues that making ontological claims in contravention to Church doctrine was regarded as hazardous, and that Osiander felt it was safer to stay with the precedent in Mediaeval scholarship to claim only that the cosmos behaved as if the theory were so: as theoretical possibilities only. This denied to Copernicus the credit for the impetus to development in theorising that is claimed, above, for Galileo. More significantly, it changed the ontological beliefs entailed by interpreting Copernicus as proposing a system of hypothetical, rather than real, entities. The effect of Osiander’s change was to argue that scientific theories are *instrumental*, and do not describe a reality. *Instrumentalism* became an enduring characterisation of science belief systems, and is opposed to *realist* interpretations of science:

> [Instrumentalism is the] view that a scientific theory is nothing more than a device or instrument for yielding correct predictions about the course of Nature, and theories must therefore be assessed not as true or false, but only as effective or ineffective as prediction … [G]ood theories generate reliable predictions, but have no real explanatory function. (Richards 1983b, p. 209)

Strong instrumentalism denies that theories can ever be true; a weaker instrumentalism allows that some theories might be true, but we can never know if they are. Instrumentalism has traditionally been one of the arguments against realism, and remains a central belief in some contemporary characterisations of science that deny an independent and knowable reality, such as some post-positivist empiricist and constructivist belief systems. Against this, post-positivist versions of realism and constructivism claim that scientific activity is intelligible only if it does manipulate an external reality, even though our knowledge of it is imperfect (Bhaskar 1983k; Knorr Cetina 1995).

Galileo’s was not the only contribution relevant in that period. The Cartesian belief system proposed by Rene Descartes was very influential for several generations, being the most ambitious attempt at a cohesive world-view or belief system since Aristotle (Dijksterhuis 1986, p. 408; Singer 1959, p. 264). Descartes’ conception enabled strong ontological claims to be made about the relationship of mathematics to the cosmos, displaying ‘the fundamental correspondences of number and form’ (Singer 1959, p. 226). This belief has remained down to the present day:
... Kepler and Galileo were deeply convinced that ... the structure of the world was essentially mathematical in character and a natural harmony existed between the universe and the mathematical thought of the human mind.

Now the standpoint taken by Descartes cannot be better described than by saying that by carrying this conception to its extreme he virtually identified mathematics and natural science. Natural science is mathematical in character not only in the wider sense that mathematics ministers to it ... but also in the much stricter sense that the human mind produces the knowledge of nature by its own efforts in the same way as it does mathematics. (Dijksterhuis 1986, p. 404)

The final claim by Dijksterhuis represents a version of constructivism that is not shared by all. However the belief that mathematics describes the objects of scientific study is consistent with a wider variety of views, as in Davies, above.

More recently, Redner (1987) has argued that what he terms the World science that has emerged in the twentieth century is fundamentally mathematical in ways not well appreciated even by many scientists. Physicists use increasingly complex mathematics as their means of analysing and describing the cosmos: the mathematics of the very large (cosmology) and the very small (particle physics) is increasingly removed from experimental testability (Hawking 1988; Davies 1988; Davies & Gribbin 1991). Richard Feynman is an example of a physicist who has cautioned against the substitution of mathematics for experimental testing.
2.9 Other metaphysical beliefs

Science is also characterised by beliefs about the ultimate nature of being (ontological beliefs). A significant change used to characterise the Scientific Revolution was the rise of the belief that the material world ultimately comprises interacting particles. We have seen that Collingwood (1945, pp. 96-98) drew a connection from Copernicus's denial of a special place in the universe for the earth, to a denial of an organic (and ensouled) cosmos, and to a belief in the uniformity of Nature, including uniformity of substance. These changes entail metaphysical beliefs about the ultimate nature of substance. In this period the overall shift of these beliefs were to a cosmos made of tiny corpuscles arranged in empty space, rather than being continuous as in the Aristotelian belief system. We have noted in an earlier section that by the seventeenth century there were several, competing belief systems about the ultimate nature of substance in the cosmos, summarised as the Aristotelian, alchemical (Spagyristic), Cartesian and atomistic systems. These broad characterisations characterise shifts from and to belief systems by changes in basic ontological beliefs. The first two were persisting mediaeval belief systems, as we have seen, and the second two were emergent or re-emergent belief systems, which we will discuss briefly below. Galileo's contribution is included as representing something of a watershed between the old and the new belief systems.

The Aristotelian belief system

Both Aristotle and Plato had rejected the belief that the cosmos was composed of discrete, indestructible entities called atoms as proposed by Democritus (c460-371BC), on the basis that such a belief entailed beliefs in self-moving bodies and the existence of a vacuum in which they moved. Aristotle did allow, however, for a minimum size of the interacting entities:

Elsewhere [Aristotle] argues against Anaxagorus that divisibility is subject to a natural limit, which could not be exceeded without impairing the substantial form. Each substance is thus assumed to possess its own characteristic smallest particles, its minima naturalia, which might be compared to the molecules of later chemistry. (Dijksterhuis 1986, p. 24)

Aristotle actually argued this in terms of living things, and it is unclear whether this claim was made of inanimate entities. However it was interpreted by the scholastics that all substances comprised their own minima naturalia, and so it is necessary to distinguish this Aristotelian-scholastic belief from the atomism of Democritus. Dijksterhuis (1986, p. 205) has argued that there are four such differences. (1) Minima naturalia have the properties of the macro-body they compose, and so differ qualitatively from each other; Democritean atoms differ only as a result of differing numbers. (2) Minima have a characteristic size for each substance; atoms exist in differing sizes. (3) The geometric form is irrelevant to
minima, but important for atoms. (4) Chemical reactions, in which the new substances have different chemical properties, are accounted for by the simple spatial rearrangement of atoms, but by the internal transformation of minima. Scholastic treatment of this belief system was limited to metaphysical speculation and reliance on doctrinal interpretation, and the limits of this approach are clear when compared with the competing belief systems described below.

The alchemic (Spagyristic) belief system

The Swiss Paracelsus (1493-1541) is associated, despite a few examples from antiquity and the period of Islamic science, with the beginning of the treatment of medical conditions with chemicals, an activity known as iatro-chemistry (Dijksterhuis 1986, pp. 279-281; Singer 1959, pp. 199-200; Brock 1983, p. 118; and Sheppard 1983b, p. 198). His contribution to science is intriguing and mixed, partly due to his iconoclastic personality and obscure writing, and partly to his advocacy of a mixture of hermetic beliefs that were popular at that time. In common with what Dijksterhuis (p. 278) called the ‘Aristotle-myth of Scholasticism’, Paracelsus opposed any corpuscular conception on the basis of needing to ‘understand how the whole can be something else than the sum of the parts’ (Dijksterhuis 1986, p. 281). In conflict with the Aristotelian system of four elements, however, Paracelsus claimed that substances are made from three Principles which give each substance its characteristics. Rather confusingly, the three names were already given to particular substances: mercury and sulfur had been identified as principles by Islamic scholars, to which Paracelsus added salt. On Singer’s account, the Principle mercury represented the nature of metals, sulfur represented combustibility and changeability, and salt represented resistance to fire. On Dijksterhuis’ account, they represented respectively the active spiritual in Nature, the mediatory principle and the passive corporeal. This variation of interpretation is consistent with the imprecise conceptions common to alchemic and mystical belief systems of that time. Paracelsus’ contribution remains important, though. He was influential in reaffirming some useful empirical alchemic doctrines, such as that the substances comprising a compound can be retrieved from it. Also, the assumption of the tria prima reoriented the focus of others away from acceptance of doctrine, as in the Aristotelian-scholastic belief system, and toward observation of Nature.

Galileo's ontological beliefs

Galileo’s change of thinking about metaphysical entities is regarded often as a watershed between the old and new belief systems, as we have noted. The Aristotelian-scholastic idea of the irreducible essence of entities - their qualities - was they could be either sensed directly (manifest) or inferred (hidden or occult). The weakness of this system was exposed progressively, as the Hermetic philosophers in particular resorted to providing explanations by introducing new qualities in an ad hoc fashion (Heilbron 1983d, p. 353).
That is, they proposed explanations by inventing new terms that were labels only, and did not add to the testable meaning of existing concepts or beliefs. (There is a parallel with developments in twentieth century physics: Feynman among others has criticised this field for the tendency to provide explanations by postulating mathematical entities, rather than basing them on empirical data).

In contrast to these mediaeval beliefs, Galileo’s ontology is generally represented as a twofold change: what qualities represent, and their relationship to mathematics. Mathematical beliefs of the cosmos entail decisions about what aspects of Nature can be quantified legitimately, and what cannot. Galileo’s contribution was to provide a basis for these decisions. In doing this, Galileo drew upon the distinction made by Democritus (c460-371BC) between two groups of qualities of Nature:

[T]hose qualities inherent in and those produced by inorganic bodies: shape, size, location in space and time, and motion were quantifiable, mathematically manipulable, and, since they comprised the reality behind the experience, the business of physics; all other qualities - taste, colour, heat, sound, etc. - were in the observer, not in Nature, and originated with the activity of variously shaped bits of matter on his [sic] sensory organs (Saggiatore (The Assayer, 1623)). This radical demarcation between what Robert Boyle later called primary and secondary qualities became the metaphysical cornerstone of succeeding versions of corpuscular philosophy. (May 1983, p. 82)

That is, there were two basic shifts in beliefs at that time: a belief that metaphysical qualities are either inherent in bodies or are produced by them, and a belief that primary qualities can be represented mathematically. These two beliefs alone are sufficient to characterise the classical physical science that developed from that time, even down to today, whereas the beliefs they replaced are recognisably those of antiquity.

The precise relationship between mathematics, ontology and scientific experiment has remained a subject of discussion from that time, continuing the dialogue between the beliefs expounded by Plato and Aristotle. This is well put by Oldroyd who, in discussing Galileo’s speculations about the nature of the cosmos in The Assayer, observes:

Galileo gave an important statement in relation to the question of mathematical abstraction, in which we can recognise what has come to be known as the doctrine of primary and secondary qualities ...

What Galileo seems to have [said] was that a body, to be a body at all, must have at least the qualities of shape, position, motion or rest, contiguity (or spatial relation to other bodies), and number. Such so-called primary qualities really inhere in bodies themselves; others such as taste and feel, which came to be called secondary qualities, only inhere in the mind of the observer. This is an epistemological/ontological doctrine that was to engender a considerable amount of philosophical discussion in the seventeenth and eighteenth centuries ... The point to be noted here is that Galileo seems to have distinguished those qualities that were susceptible to investigation by means of mathematical analysis from those that were not. Here, then, we have one of the chief sources of the doctrine of primary and secondary qualities, which ... was to interact in philosophically interesting ways with the seventeenth century doctrine of matter - either corpuscularian or atomistic. (Oldroyd 1989, p. 59)
Oldroyd's closing comments here, differentiating corpuscularian and atomistic conceptions, uses a restricted sense of matter being corpuscular as advocated in the Cartesian philosophy following Descartes, and contrasted with the atomism revived by Gassendi. These two ontological beliefs are outlined below.

The Cartesian belief system

The fourth belief system, the Cartesian cosmology, is only part of Descartes’ vast contribution to Western European thought. Its basic ontological beliefs revised metaphysical qualities, largely as mathematical entities:

Descartes regards the universe as infinite and devoid of any empty space. The primary quality of matter is extension, but there are also derived (not secondary) qualities of divisibility and mobility, which are created by God. (Singer 1959, p. 262)

[In the sense of] reduction of phenomena to kinematic or geometrical quantities (corpuscular philosophy), [Cartesian cosmology] limits the ingredients of physical theory to size, shape, motion, impenetrability, and, perhaps, inertia [and is] to be opposed to Newtonian [cosmology]. (Heilbron 1983a, p. 53)

Although Cartesian cosmology had considerable currency for a time and remained influential in France until the mid eighteenth century, it failed to account for a number of phenomena such as planetary motion as described by Kepler’s laws. It was inconsistent with and defeated by Newton’s physics (Singer 1959, p. 262). Nonetheless, it was Descartes who, with Gassendi (1592-1655) and Boyle (1627-91), was mainly responsible for popularising the mechanical philosophy in the seventeenth century. It was, however, the conception developed progressively by Boyle, Newton and then Dalton (1766-1844) that ultimately prevailed, and that Oldroyd characterised as atomistic in the passage above.

The atomistic belief systems

The fifth system of beliefs current in Europe in the middle of the seventeenth century was that of Gassendi who, like Galileo and Descartes, developed physics as a study of matter and its motion. Gassendi’s cosmos represented a revival of the atomism of Democritus and Epicurus, although with the initial creation of atoms and their motion being given by God. Subsequent to this initial divine act, Gassendi’s cosmos was entirely explainable in terms of primary qualities:

[For Gassendi, everything within the universe could be explained by] the magnitude, arrangement, shape, and motion of invisible, extended, physically indivisible, ponderable, impenetrable atoms moving in an infinite void. Motion is rectilinear when unconstrained, indestructible, and non-transferable ... Atoms act upon one another only by impact ... (May 1983, p. 82)

The details of the nature of the interactions between these four competing belief systems in seventeenth century Europe are beyond the scope of this section, but their more or less concurrent existence certainly serves to highlight the role of basic beliefs in the development of science and characterisations of it. In any event a more or less consensus
Appendix B.2: Belief system

view emerged which is summarised by Harré as the *Corpuscularian system* in its more general sense:

'(i) Ultimately there is only one substance, and change is possible because it is divided into units, which are capable of motion and hence rearrangement.'

'(ii) The arrangements of the corpuscles is the real essence of bodies, and defines their primary qualities.'

'(iii) Geometry as the science of shape, and mechanics as the science of motion are the fundamental sciences.'

'(iv) Changes in our ideas of secondary qualities are the result of changes in the arrangement and state of motion of constituent corpuscles.'

'(v) Basically the only real happenings were redistributions of motion brought about through action by contact.'

'(vi) The ultimate properties of corpuscles were their power to fill space (their extension), and their power to resist instantaneous increments of motion (their inertia). (Harré 1985, p. 138)

Harré continues that Boyle attempted a proof of corpuscularianism, but Boscovitch showed incoherencies and contradictions in ontological beliefs of ‘mechanical action by contact among solid, incompressible bodies’ (p. 138).

At this time, some who advocated atomism further thought that the corpuscles could be derived by the processes of analysis (Harré 1985, p. 128). Boscovitch’s objection to a belief in corpuscular matter anticipated later developments in physics and metaphysics, that interpreted the cosmos by *fields* rather than entities or *things*:

> If a material thing is regarded as a perduring occupant of space capable of being perceptually identified, then many objects of scientific knowledge, though dependent for their identification upon material things, are immaterial. Indeed, R. J. Boscovitch (1711-87) and I. Kant (1724-1804) and others have argued that the ultimate objects of scientific knowledge, wherever the ‘ultimate’ may fall for us, cannot be thingish (corpuscularian), but must be field-like. (Bhaskar 1983f, p. 249)

Even though the objections of Boscovitch and others proved to have more currency in later twentieth century science, atomistic or corpuscularian notions from that time remain in the popular consciousness today, perhaps due to their compatibility with the simpler atomic models proposed earlier in the twentieth century. For example, mass is treated as a property in Newtonian physics but as a relation in Einsteinian physics (Chalmers 1982, p. 162); the latter is a difficult concept for those whose idea of matter is ball-and-stick models of molecules.

Bhaskar (1989, pp. 15-18) rejects both empiricism and idealism/constructivism on the basis of their shared ontology, that is, their shared beliefs about being. This view is described in discussion of experimentation in Appendix B.5, and mentioned in section 2.10 below, on beliefs about experimentation.
2.10 Beliefs about experimentation

Beliefs that experimentation is an appropriate way to gain knowledge of the material world have characterised science, particularly from the Scientific Revolution, down to the present. These beliefs served to enable and influence experimentation, and in turn were influenced and legitimised by the considerable experimental successes from the sixteenth and seventeenth centuries onwards. Borhek and Curtis, for example, link the capacity for experimentation by any suitably trained person directly to the nature of the scientific belief system (see summary statement 77). Bhaskar has argued that the very intelligibility of the experiment rests on particular beliefs about Nature:

At the experiment’s core is the notion that the conditions for producing a given effect can be separated into independently variable factors, in such a way as to demonstrate how the factors behave in their natural (i.e. the non-experimental) state. (Bhaskar 1983c, p. 136)

Some of these beliefs date from antiquity. For example, Aristotle’s inductive-deductive method rests on the assumptions or beliefs that the cosmos is regular, not capricious, and free from wilful supernatural intervention. As we have mentioned, the decline of both mediaeval scholasticism and magical beliefs represented the decline of beliefs that were antithetical to experimental interrogation of Nature. This is not to say that the only science activity of inquiry is experiment, because clearly some fields, such as astronomy and medicine, have made advances even when a strict sense of experiment has not been possible. Nonetheless, experiments are characteristic activities of science, as discussed in the companion chapter and Appendix B.5 on activity; the point here is that they are made possible and used because of beliefs about the nature of the cosmos and the appropriate orientation to it.

The emergence of beliefs that entailed experimental inquiry of Nature competed with and contributed to the decline of the other belief systems, although they emerged over some time (Bhaskar 1983c; Oldroyd 1989, pp. 149-56). Bhaskar (1983c) has listed several beliefs that proved to be critical, and their proponents:

- Belief in the need for ‘independent testing of the principles reached by induction and active experimentation to extend the factual (or inductive) basis of science’, first attributed to Robert Grosseteste (c1168-1253) and his pupil Roger Bacon (c1219-92) (Bhaskar 1983c, p. 136).
- Belief in ‘the need to differentiate accidental from essential (or necessary) correlations and to decide between alternative hypotheses for the data’, attributed to Francis Bacon (1561-1626) (Bhaskar 1983c, p. 137).
- Logic and methodological beliefs, in the methods for establishing agreement, attributed to Duns Scotus (c1266-1308), and difference, by William of Ockham (c1285-1349), as part of the development of a logic of experimental
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inquiry, with various contributions from Francis Bacon, Isaac Newton and David Hume (1711-76).

- These culminated in the five Canons of induction proposed by John Stuart Mill (1806-73). Although commonly discussed as elements of activity, Mill's Canons are actually principles for conducting inductive inquiry. That is, they are elements of a belief system; this is discussed in section 3 of Chapter 7, and induction and experimentation are discussed in Appendix B.5 on activity.

The point here is that a particular belief system, through its beliefs, assumptions and criteria, justified and gave form to an experimental approach that characterised western European science from that time down to the present. It included beliefs about the proper orientation toward the material world in order to gain knowledge of it.

Bhaskar (1989) has argued that of the three main philosophical characterisations of science that comprise the current consensus - post-positivist versions of empiricism, idealism and realism - experimentation is intelligible only according to the beliefs of scientific realism. Broadly, he claims that there are three domains of reality, and the empiricist and rationalist traditions, which share an ontology that Bhaskar calls empirical realism, collapse the three domains of reality into one. In his view, empirical realism is flawed because of several beliefs about being (ontology) and knowledge of being (epistemology). First, we shape our beliefs about the nature of the cosmos according to what we experience and reason, whereas empirical realism defines Nature (ontology) by categories of experience (epistemology). The purpose of empirical realism is mainly to justify belief; therefore it seeks certainty and in doing this it examines only certain phenomena. Secondly, empirical realism assumes that the world is essentially experienciable, whereas scientific realism assumes that some things happen to be experienciable and are therefore significant for science. Thirdly, empirical realism does not account for the fact that the circumstances where experience in science is epistemically significant are socially produced circumstances (Bhaskar 1975, p. 28). Thus, according to empirical realism, the world is human-dependent (empirical) and knowledge is activity-independent (asocial). On the other hand, scientific realism characterises science by consciously and socially produced knowledge of an objective, or intransitive, world. Thus experiments need to be recognised as consciously contrived manipulations of reality: the world is human-independent (transcendentally real) and knowledge is human-dependent (social).
2.11 Models and metaphors

Science is characterised often by models and metaphors that are used to represent elements of belief systems: fundamental beliefs, assumptions, values and attitudes. Models and metaphors are useful because they succinctly represent complex ideas. Scientists and others use a variety of models, both formal and informal, but the representational function of the language overlaps with that used for metaphors: sometimes there can be no meaningful distinction between labelling something an informal model or a metaphor, so this section will deal with both. The key characteristic is the use of language for representation, which applies to metaphors and models of all types:

Semantically, metaphor can be understood as a transfer of a term between different contexts of meaning. Metaphors thus emerge, in the ‘hermeneutic’ approach, as crucial for understanding conceptual transfer between scientific disciplines, or between science and other areas of culture. (Golinski 1990, p. 116).

Metaphorical redescription (e.g. light as waves rather than particles) is often held to be central to theoretical changes in science. A new metaphor does not merely provide ‘answers’ to pre-existing ‘questions’: rather, by radically recasting our perceptions, it creates new problems, observational terms and experimental strategies, and hence largely determines the nature of empirical results ... Analysis of metaphor illuminates such problems as how to talk about unobservables, and the nature of changes in the meaning of theoretical terms. (Edge 1983, p. 264)

[Models are] an interpretation of a formal system and/or a representation, normally by analogy (but sometimes by metaphor), of one thing by something else. Models may be made for mnemonic, heuristic, explanatory, or test purposes. (Bhaskar 1983h, p. 272)

The characterisation of the Scientific Revolution partly by the adoption of mechanistic beliefs is an example that can be considered as both model and metaphor of a mechanical system. It uses well known images such as clock mechanisms to embody the notion of similar interactions between corpuscles or atoms (Collingwood 1945; Singer 1959), but its interpretation as model or metaphor depends largely on the interpretive viewpoint.

For example, Needham (1969, including summary statement 72) implied or seems to imply the necessity of a mechanical model of Nature in order to make the shift from primitive or mediaeval science to modern science. The assumption that any science in any culture would need to progress through a period of adopting a mechanical model, as the Europeans did in the seventeenth century, in order to finally develop modern science is a strong argument for the power of models and metaphors. (Needham’s other assumption, that the Western European conception of science is the ‘best’ conception in any case, raises questions of historical and socio-cultural interpretation that are discussed in sections 2.6 and 2.12 of Appendix B, and in the companion chapter on context.) The historical use of the mechanistic belief system or mechanical philosophy, however, is worth mentioning in
Locke intended his empirical philosophy to be used as an underpinning for, or philosophical justification of, certain major metaphysical assumptions of the science of his day, being chiefly concerned with giving a warrant for the mechanical philosophy and principle of causality - that like causes are always followed by like effects, every effect having a cause, there being no uncaused (physical) events. The mechanical philosophy in the seventeenth century took on a great variety of forms, but in general it assumed that there was a world of atoms or corpuscles below the level of the visible world. And the coalitions and interactions between these small particles, and perhaps their intrinsic attributes, might be held responsible for, or explain, the phenomena of the world of everyday experience. In addition, the mechanical philosophers supposed that all physical, chemical and biological phenomena, and to some extent mental phenomena as well, were to be accounted for in mechanical terms. So in many seventeenth- and eighteenth-century scientific writings we find a heavy reliance on mechanical models and analogies. Both Descartes and Newton were, in their different ways, mechanical philosophers. Boyle and Hobbes were philosophers of this kind *par excellence.* (Oldroyd 1989, p. 87)

So regardless of the argument over the *necessity* of a mechanical model, its widespread and long-term deployment indicates its *usefulness*. Consideration of usefulness implies, of course, some context in which it was useful, and the use of scientific ideas in the industrial revolution in Europe is taken up in the companion chapter on context.
2.12 Other belief systems

Some accounts characterise a western European scientific tradition by contrasting its fundamental assumptions and beliefs with those of other cultures. This raises several fundamental difficulties in using the criteria of western science to judge traditions in non-western cultures, which are discussed above and in the companion chapter on context. One is the very use of the word *science* in non-western contexts, and another is the (often unrecognised) assumptions used in making cross-cultural comparisons: hence the decision, made in the companion chapter on context, to use the term *natural philosophies* rather than become enmeshed in disputes about what constitutes science in non-western contexts. This section gives some examples to show how the literature characterises contemporary western European science by differences and similarities between belief systems, in particular the underlying beliefs about the cosmos (ontological beliefs) and the orientation necessary to have knowledge of it (epistemological beliefs).

Briefly, several themes emerge in accounts that contrast western European science with other natural philosophies, where the differences between western and non-western belief systems arises from one or more of these themes. The first theme is the identification of the cosmos with a god or deity; that is, a belief in *pantheism*. Another is a belief that events in the cosmos are cyclic, often accompanied by related beliefs in reincarnation. A third is a belief that the cosmos and its entities are *organic*, that is, an *animistic* view. Arising from one or more of the first three themes, the fourth theme is the belief that the cosmos is by its nature unknowable by humans, and it is this belief that is argued to characterise the significant difference between western European science and other natural philosophies.

As we have seen, the Ionians adopted an inquisitive orientation to a cosmos explained in naturalistic terms. The accounts reviewed here contrast this with other metaphysical views that did not admit human inquiry. The proper orientation in those cases was to accept that the way of the world was as it was, and could not or should not be interrogated by humans. This is not to say that the Ionians' belief systems were immediately and completely distinct from other belief systems, such as those in India and China at that time, because they were not. For instance, Jaki (1974) noted strong cyclic elements in various Greek cosmologies, including Aristotle’s. On Collingwood’s account, Thales believed the cosmos to be animistic in a fashion not dissimilar to what we have discussed:

... Thales conceived the world of nature as an organism: in fact, as an animal. This is confirmed by the fragments which have come down to us of Thales’ own utterances. According to these fragments, Thales regarded the world (the earth plus the heavens) as something ‘ensouled’, a living organism or animal, within which are lesser organisms having souls of their own; so that a single tree or a single stone is, according to him, both a living organism in itself and also a part of the great living organism which is the world. One such organism within the world
is the earth; which Thales, we are told, conceived as floating upon an ocean of water. Since he certainly thought of the earth as alive, and certainly thought of it and everything in it as made of water, and probably also thought, as his pupils certainly thought, that everything in nature was constantly passing away and therefore in need of constant renewal or replacement, he may possibly have conceived the earth as grazing, so to speak, on the water in which it floats, thus repairing its own tissues and the tissues of everything in it by taking in water from this ocean and transforming it, by processes akin to respiration and digestion, into various parts of its own body. We are told, moreover, that he described the world as something made by God. That is to say, the vital processes of this cosmic organism were not conceived by him as self-existent or eternal (for he said that God is 'older' than the world) but as depending for their existence on an agency prior to them and transcending them. (Collingwood 1945, p. 31)

This general world view clearly bears greater similarity to the Chinese and other early cosmologies than it does to post-Renaissance Western European science. A general world view, while it is part of a characterisation of a natural science, is therefore not the determining characteristic. The present thesis argues that any world view arises from a belief system that only partly characterises a science or natural philosophy.

Likewise, some commentaries on the Aztecs contrast their beliefs with those of the Western European scientific tradition (Soustelle 1964; Jaki 1974). Aztec cosmology drew on earlier cultures, such as the Mayas, and was extant up until the European invasion in 1519. Briefly, the Aztecs believed that the cosmos was grim, demanding and capricious and thus not subject to human comprehension; the proper orientation to it was therefore one of submission and awe, not investigation. Two particular features of the Aztec cosmology at this time should be noted. The first is the integral role gods were believed to have in both the creation and continuation of the cosmos. The second is the centrality of cycles in the Aztec cosmology, in which the physical manifestation of the world, including space and time, was subordinate to the cycles. Soustelle (1964) has argued a that there was a significant link between the cyclic view of Nature - in which special significance was attached to the regular reappearances of the sun and Venus, and of flowers following the rains of the new season, for example - and beliefs in human reincarnation, which dominated 'the whole of ancient Mexican thought, and their whole vision of the world' (Soustelle 1964, p. 118). These beliefs were central to the Aztec conception of the cosmos and the destinies of people, and from them arose attitudes about the appropriate orientation to this cosmos, as we shall see.

The Aztecs believed the cosmos to have been created and ruled by many gods - a sun god, rain god, moon god, maize god and so on - to whom worship and sometimes sacrifice was believed to induce the god’s favour and, through totemic association, the desired outcome. The sun, which was central to Aztec life, was believed to have been created by one god throwing himself into a fire: the sun’s continued movement was secured by human sacrifice and the offering of blood, without which it would stop and the world would end in darkness and disaster. Thus basic beliefs about the nature of the cosmos led to behaviours of sacrifice and worship as appropriate ways to interact with Nature.
Appendix B.2: Belief system

The Aztecs conceptualised the earth as symbolised by, but not literally, a ‘monster with wide-open jaws which swallows the sun in its setting, the remains of the dead and the blood of the sacrificed’ (Soustelle 1964, p. 116). The significance of this belief here is not the image itself of the monster, but that the earth was organic (and therefore having similar characteristics to humans), required sacrifices of blood, accounted for other beliefs about the dead, and was a fearful image, inspiring awe and terror. Significantly, it did not invite inquiry as to its nature beyond this image.

To the Aztecs, units of time recurred, something like the seven recurring day units in our calendar but also physically recurring. The cyclic nature of the cosmos was very significant, in that it allowed no human escape and against which there could be no human intervention or control. The belief that there could be no human intervention in Nature is also fundamental. The world in which the Aztecs lived was believed to be the fifth such world, the previous four being represented by the four suns in Aztec calendars. Like the previous worlds, the world of the Aztecs was believed to be ephemeral, an illusion of reality beyond which were terrible monsters, and that would end catastrophically. The complicated system of Aztec cycles was set out in the Aztec calendar, which also formalised the fundamental beliefs that characterised the Aztec conception of the cosmos, by linking ontological, religious and mystical beliefs. Thus a system of signs, numbers and influences were assigned to the cycles, and to gods, cardinal points (north, south, east and west) and qualities; space and time were undistinguished, as multiple instances of space-time:

The qualities peculiar to each of these ‘moment-loci’ ... follow one another cyclically in abrupt, total change according to a determinate rhythm, in conformity with an everlasting order. (Soustelle 1964, pp. 123-4)

While it is tempting to foreshadow here Einstein’s notion of space-time, Soustelle’s point is that the Aztecs’ idea was too imprecise to measure, and in any case was believed to be beyond human control. Once again, basic ontological beliefs both provide for and limit the concepts available for further thinking about and investigation of the cosmos. In this instance, the effect was to entail a belief that events concerning nature and of humans were localised and disconnected:

In the absence of a generalised notion of space and time, the basic conceptual foundation also was missing for a consideration of the succession of events as a rationally explorable chain in which each link causally acts and is also acted upon (Jaki 1974, p. 52).

The combined effect of these beliefs profoundly influenced the orientation of the Aztecs to the universe. This is to be expected: if one holds certain beliefs to be true then a certain orientation - meaning an attitude, a belief in what actions are effective in relation to Nature - necessarily follows. For example, given the belief that Nature was cyclic, terrible and disjunctive, the proper orientation was to submit to the
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...cyclic, rhythmic, and basically violent transformations of nature around [them] ... Indeed, nature for the Aztecs was a source of fear which they ultimately came to honour and worship (Jaki 1974, pp. 52-3).

Soustelle also characterises the Aztec orientation to the cosmos as a reactive attitude, clearly related to a set of beliefs:

At bottom the ancient Mexicans had no real confidence in the future, their fragile world was perpetually at the mercy of some disaster: there were not only the natural cataclysms and the famines, but more than that, on certain nights the monstrous divinities of the west appeared at the crossroads, and there were the wizards, those dark envoys from a mysterious world, and every fifty-two years there was the great fear that fell upon all the nations of the empire when the sun set on the last day of the ‘century’ and no man [sic] could tell whether it would ever rise again. (Soustelle 1964, p. 114)

Quite clearly, such attitudes are fundamentally at odds with a belief that the cosmos could be subject to inquiry. Another attitude, concerning the orientation to the cosmos, arises from the belief that the fate of each individual was subject to strict predestination:

Indeed, man [sic] had but an insignificant place in the Mexican vision of the world. He was governed by predestination; neither his life nor his after-life were in his own hands, and determinism ruled every phase of his short stay on earth. He was crushed under the weight of the gods and the stars: he was prisoner of the omnipotent signs. ... Horror and horrifying monsters surrounded him on all sides: ghosts and apparitions made their dark signals of despair. (Soustelle 1964, p. 126)

An attitude of resignation and defeat is implied as arising from the belief in predestination. Soustelle argues that belief in predestination influenced what it was in Nature that the Aztecs looked for and, by implication, their notion of cause and effect. Thus, the interpretation of events was in terms of omens:

Minds that were so very much under the domination of fate could not but be uncommonly sensitive to omens, whether they were drawn from little everyday happenings or from extraordinary phenomena. An unaccustomed noise in the mountains, the cry of an owl, a rabbit running into a house, or a wolf crossing the road foretold disaster. (Soustelle 1964, p. 125)

Belief in omens represents a particular belief in cause and effect. The relative significance of ordinary and extraordinary events and their explanations is a recurring issue in characterising natural philosophies. A belief in omens is consistent with interest in extraordinary, rather than ordinary, phenomena. Thus an uncommon and presumably unexpected event would prompt the search for an other uncommon event that could be deemed to be associated with it. The associated event is then presumed to have been an omen for the first event, and there is interest in future in being watchful for further omens so that future events can be predicted. This has some similarities with post hoc analysis in the Western European scientific tradition, which would also seek extraordinary phenomena that closely preceded an extraordinary event to try to establish a cause and effect relationship. But the use of observational data - of symptoms or phenomena - to make naturalistic predictions or construct explanations is different to an interpretation in terms of omens, which are non-naturalistic.
As a final comment on the Aztecs, the belief in predestination also related to the calendar, as mentioned above, by linking ontological and mystical beliefs, and by assigning various significances to the cycles, ontological qualities, gods and the cardinal points. This enabled a person’s destiny to be worked out using the complicated calendar. The Aztecs, like all central American peoples following the Mayas:

[They] worked out complex chronological systems, and this for two purposes: the first was to find fixed points in order to understand and foresee the succession of natural phenomena, the seasons, and the movements of the stars, and so to regulate the rites that were necessary to their proper sequence; the second was to determine the fate of each and the fortunes of each undertaking by means of a body of portents which made up a coherent whole quite as ‘scientific’ for those people as our rational explanations of the world are to us. (Soustelle 1964, p. 124)

The closing comment from Soustelle illustrates two points. First, it underscores the point that each belief system made sense within its own cultural context. Secondly, the language he uses nonetheless indicates an analysis in terms of our (western European) beliefs: their belief system is ‘quite as “scientific”’, while ours are ‘rational explanations’. The unacknowledged bias in such claims does not alter the fact that nonetheless ontological and epistemological beliefs are used in the characterisation of science. A comparison of beliefs between cultures, and the resulting insights into the nature of beliefs, will be given later and address the effects of such cultural biases. The point here is that the Aztecs claimed observational support of the cosmos for their beliefs, which was Soustelle’s final point, above. And in turn, this raises a question which will recur in this chapter, as to how these differ from beliefs held in the Western European scientific tradition, which also claims to support ontological beliefs with observations. Examples from other cultures will need to be given before a satisfactory analysis can be attempted.

**Hindu (Indian) cosmology**

A comprehensive modern western analysis of Hindu science has yet to be done, and would be problematic (Ronan 1982, p. 187). Nonetheless, there is sufficient known of Hindu science to serve as an example here. As for the Aztecs, the cosmos was believed to be cyclic and animistic, but is a clearer example of pantheism:

The basis of Hinduism is an animistic religion with a large number of different gods not unlike those of the Egyptians, and the religious activities of the Hindu are devoted to ritual observances which permit every aspect of life to come into tune with these various gods and spirits. For it is accepted that the universe is in danger of being destroyed by chaos, and the sacrifices offered by men could help to strengthen the gods ... This belief has been important in the mingling of physical and spiritual studies as can be seen in the widespread practices of yoga and other forms of asceticism. The Hindu religion has encouraged spiritual inquiry, and has developed lofty concepts of the unity of Nature and of the Divine Principle ... (Ronan 1982, p. 188)
Jaki points to pervasive references in ancient Hindu literature to a cosmos identified with an 'undifferentiated, eternal' being, the Brahman. There is again a world-view that discouraged inquiry, or what Jaki characterises as rational inquiry:

Escape from [the preoccupation with the wheel of cycles] was well-nigh impossible either emotionally or conceptually. Only confusion in logic could be generated by a pantheistic description of the cosmos in which the supreme deity was defined as being cause and effect simultaneously ...

... (I)n the universe everything was the prey of blind, capricious convolutions or cycles. The laws of those cycles permitted no rational explanation, as it was a patently absurd task to make a critical analysis of the breathing of Brahma, which allegedly regulated the universe. If man [sic] was a tiny part of a huge cosmic animal, there remained little if any psychological possibility that he could ever achieve a conceptual stance which would put him outside the whole for a critical look at it. (Jaki 1974, pp. 19-20)

Once again, the particular concepts in themselves are not the most significant factor. Concepts such as Brahma are recognisably not part of the Western European scientific tradition, but it is also true that many concepts within the Western European tradition have gained and lost favour. Thales' answer of water is just one such example. On Jaki's account, it is the belief that the universe was capricious and that humanity could only be part of a living universe, and the attitudes attendant to those beliefs that works against a scientific tradition (like the western European one). He argues that the underlying belief that the cosmos was a deity made an understanding of the cosmos futile and denied a belief that the cosmos is open to inquiry.

Chinese natural philosophies

In China, as in Mexico and India, the orientation to inquiry was shaped by a set of general beliefs about the cosmos, or metaphysics. The example of China is worthwhile pursuing in a little more detail, because of the interesting questions about science raised by comparisons between the Chinese and European situations. The companion chapter on context discussed the difficulties in interpreting natural philosophies in non-western cultures, but used China as an example. The particular example here is that there was a scientific revolution in Europe that spurred a prolonged and flourishing science tradition, but not in China, even though many developments in Chinese natural philosophy were concurrent with, or predated, similar developments in Europe. Jaki (1974) and others have characterised this as a 'failure' of the Chinese, but as the companion chapter on context discusses, this is a contentious judgement. The point here is that beliefs are central to these interpretations.

Chinese history shows periods of significant practical scientific and technological achievement, long periods of peace, 'material prosperity, active social interplay, creativity of mind, and possibly of contacts with other cultures' (Jaki 1974, p. 31). Cultural achievements were passed on from generation to generation. The Chinese made comparable...
developments in knowledge and technologies to the Europeans, and in many cases Chinese inventions preceded European equivalents by centuries:

It was around 350 BC. that the astronomer Shih Shen drew up his catalogue of some 800 stars, and that the central storing of manuscripts got under way in the Imperial Library. In the field of technology the same age also witnessed further improvements in water works and the extension of the Great Wall ... During [the age of the Warring States (220-581)] the Chinese invented the vertical waterwheel and the wheelbarrow, devices highly indicative of continued technological interest. (Jaki 1974, p. 31)

Before the Han period (220 BC. - 220 AD.), the Chinese made effective use of horses ahead of other civilisations, and they invented the stirrup, which in mediaeval times they modified into the collar harness. During the Han period they discovered that magnetic ore indicated direction, and invented paper making. In the Thang period (618-906) they became the first to print books and make gunpowder, made great advances in crafting porcelain and developed water-driven mechanical clocks. In the Sung period (960-1279) magnets were used for travel, moveable clay types were used for printing, iron mongery was highly developed and Chinese algebra was equal to that in Europe about 1250. Yet Francis Bacon had characterised the Scientific Revolution in Europe as significant and unique because of the printing press, gunpowder and the magnetic compass!

According to Needham’s thesis, Bacon got it wrong because printing, gunpowder and magnets were developed in different cultural contexts. We will also draw attention to different bases in beliefs. Both Jaki and Needham argue that the Chinese advances were not incorporated into a theory capable of development. They conclude that the essential difference was the set of beliefs we identify in the post-Renaissance Europeans as a mechanistic conception of the cosmos, and the absence of this set of beliefs in Chinese thinking:

Needham seeks the elements that inhibited Chinese science. He enumerates various factors. To develop modern science, 'Interest in Nature was not enough, controlled experimentation was not enough, eclipse-prediction and calendar-calculation were not enough - all of these the Chinese had' (Needham, 1956). What was missing, then, was the establishment of a mechanistic philosophy. (Nakayama 1973, p. 39)

The absence of a mechanistic philosophy as the explanation, of course, may or may not be the case: noting Sivin’s caution, above, we cannot claim that this description gives an explanation of cause and effect. Just because it happened one way in Europe does not mean it was the only possible way. It is difficult to judge the likelihood of one possibility among many being the only possible cause. In any event, the mechanistic cosmology has since been rejected by Western European science. There are several possible interpretations. A belief in a mechanistic cosmos may have been a useful, and perhaps necessary, development in the Western European scientific tradition: useful or necessary to provide a model sufficiently successful to allow other belief systems to be rejected. It may also be that, among all the other developments from the time of the Renaissance onwards, a
mechanistic belief system was not necessary, nor even useful except that it did not clash and inhibit other developments. It was certainly useful in the contemporaneous advances in technology, and considering the social and economic usefulness that began to be perceived of science, the conclusion must be that the mechanistic belief was useful in the Western European context.

The Europeans’ belief in a mechanistic cosmology marked a clear difference between Chinese and European sciences. For example, Ronan’s introduction to Chinese science begins in terms of beliefs (Ronan 1982, p. 133), referring to ‘an outlook on the world and on science which was different in many aspects from that characteristic of the West.’ This general statement does gloss over the fact that there were several schools of thought that contributed to Chinese natural philosophy, and some indication of this diversity follows. Confucianism and Taoism are the two schools of thought which are most widely known in the West, although there have been contributions from other schools, such as the Mohists, the Logicians and the Legalists (Ronan 1982, p. 133).

Ronan’s characterisation of the fundamental distinction of Chinese science is in terms of fundamental beliefs about the nature of the cosmos:

But it will be a help in understanding [the Chinese’] achievements if we realise that even from very early times, the Chinese looked on the entire universe as a vast organism, of which man [sic] and the natural world were both a part. This had a profound impact on the way they explained phenomena that they observed; in some cases it helped them attain an understanding long before this was achieved in the West, but in a few instances it prevented them finding the true explanation for the way the world behaved. (Ronan 1982, p. 133)

Despite Ronan’s notion of true explanation being at odds with the post-positivist rejection of absolute truth, even a weaker interpretation of true explanation as unfalsified or strongly confirmed can still be understood in terms of a set of beliefs about the nature of the cosmos (ontological beliefs).

The similarity of the concepts described in this passage to concepts being brought to contemporary Western European science, such as the notion of Gaia - of the earth as a living system - is striking. Clearly, the same comments as applied to Nakayama’s paraphrasing of Needham’s attention to the mechanistic cosmos, above, apply here to Ronan’s attention to the organismic conception of the Chinese universe. Ronan’s equation of Western European scientific explanations with ‘the true explanation’ again reveals a lack of acknowledgment of the framework within which he was describing beliefs, and an unacknowledged assumption of a particular stance within Western European philosophy.

Some Chinese belief systems: the Mohists

There were several schools of Chinese belief, namely the Mohists, the Legalists and the Confucians, and a number of developments, that could have become antecedents for a science in the Western European tradition but did not. For example, the followers of Mo Ti (c. 500 BC. - 425 BC.) held beliefs resembling those identified with the Western European
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Scientific tradition. In something approximate to the relative status of academic and technical knowledge in Europe, the Mohists advocated:

- equality, brotherhood, and practical artisanship ... [which] had some unmistakable characteristics of scientific mentality. It was in a book ascribed to Mo Ti that there appeared definitions about space, duration, causality, geometric figures, and energy that have some depersonalised, abstract, and quantitative flavour. In addition, the Mohists strove for practical implementation of general propositions. Mo Ti himself earned fame not only for his dicta but also for the building of catapults and other war machines in defence of security and equality. But what for the Mohists was a systematic effort to control the future on the basis of past experiences, soon became branded as cheap utilitarianism and lack of refinement. (Jaki 1974, p. 25)

The Mohists consequently exerted no lasting influence on Chinese thinking, as also was the case with the Logicians and the Legalists. The Logicians were not clearly differentiated from the Mohists but did provide some philosophical explication of 'concepts (eg. white, hard, horse, etc.) as distinct from particular things' and a collection of paradoxes designed to stimulate consideration of 'fundamental questions' (Ronan 1982, p. 141).

The Legalists' belief system

In the fourth and third centuries BC the Legalists advocated a harsh, authoritarian system of social organisation, the details of which are beyond the scope of this thesis. However, their concern for prescriptive detail led to attempts to quantify observations and something akin to natural laws as in European science. This is explained in the following passage, which is quoted in full because it includes many examples of the use of beliefs and attitudes in discussing science:

But however severe and unbending the Legalists were, their efforts are important in the history of Chinese science, because it was they who began the custom of detailing everything precisely - of quantifying in numbers all conceivable matters, from the widths of chariot wheels to human conduct ...

In stressing the rule of preordained law, the Legalists came close to the concept, so strong in Europe, of the Laws of Nature. It was a natural concept in the Western world, because there were always beliefs in personal guiding deities, mostly omnipotent. They ruled man [sic] and the world around him, so the idea that things, living or inanimate, behaved according to a divinely ordained law was to be expected. But this was not so in China, where there was no belief in a personal, guiding and lawgiving deity. The universe was an organism: it operated because everything fitted into its natural place and acted according to its nature. When the Legalists fell, their scheme went with them, the stimulus to express processes in numbers could not be replaced. Chinese law could not help because it was quite different from predetermined law in the Legalist sense where every crime and punishment was quantified; Chinese law knew only the 'natural law' of custom and usage tempered by what was fair and humanely desirable. That is not to say that China had no codes of laws, but they were codes with a humanistic bias. They reflected the Chinese attitude to the universe where everything happened because of an inbuilt universal rightiness, harmony and well-established custom. Crime and legal disputes were looked on more as disturbances in man's [sic] relationship with Nature than anything else. Indeed, in the T'ang code of law it was stated specifically that it is dangerous to move from this kind of natural law to a law of legally fixed punishments. (Ronan 1982, pp. 142-3)
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The Legalists developed a link between language and ontology, which matched increased specificity in language with increasing specificity in ontology; this principle is universally applicable. The structure of Western European science as laws of Nature is explained by Western European beliefs that everything - humans and their environment - operated because they were guided by divinely ordained laws given by powerful, personal guiding deities. As discussed in the companion chapters on context and structure, this belief is considered to have predisposed the Europeans to look for lawlike regularities. However, by characterising Chinese science by a belief that ‘the universe was an organism [that] operated because everything fitted into its natural place and acted according to its nature’, Ronan draws attention to the influence of the organism metaphor: the nature of entities is explained in terms of the parts of an organism. The usefulness of beliefs in characterising science is shown later in the paragraph, for they indicate how the processes and conceptual structures of the two systems must differ when the basic beliefs are fundamentally different. The Chinese belief (or what Ronan calls an attitude) that in Nature ‘everything happened because of an inbuilt universal rightness, harmony and well-established custom’ is in itself not dissimilar to that of Aristotle. However, it does indicate a significant difference between the Chinese and (especially post-Renaissance) European ontologies, including different notions of cause and effect. The linking in China of crime and legal disputes with the relationship between humans and Nature contrasts the effect that the mechanistic, corpuscularian belief system brought to the wider ontology of post-Renaissance European science, that clearly separates social and natural phenomena and their explanations.

The Confucians’ belief system

Confucianism, following the teachings of Confucius (552 BC. - 479 BC.), developed a view of nature as cyclic and operating by ‘laws’ that were similar to social customs. As such they were subtle and subject to unpredictable changes. A central concept was li, that Jaki characterises as vaguely defined and something akin to social customs:

The ways of society and nature had to be ‘felt’, and this implied a ready acceptance of what is an invariable component of the organismic outlook on existence, namely, that every process has a rhythmic or cyclic patterning. (Jaki 1974, p. 26)

The descriptors that apply here are for a subjective, intuitive and qualitative approach, focussing on organic explanations. In 136 BC, Confucianism became the official state doctrine and as a result its influence became more entrenched. The doctrine of this time was set out in detail by Tung Chung-Shu, who presented a cyclic and organismic, or animistic, view of the world as parallel to the individual human, society and history. Thus the posture, anatomy, physiology and behaviour of the human form correlated with the earth and the cosmos in a way that reflected a belief that the human form and function reflected in microcosm the form and function of the cosmos in macrocosm. The appropriate orientation
with the cosmos was to acknowledge and respect the links between human and cosmic cycles:

The key to success and harmony was therefore one’s docility and willingness to merge into the rhythm of cosmic cycles that were also the patterns of human history. (Jaki 1974, p. 27)

As with the Indian example, it is not the concepts in themselves but the attendant beliefs and implied necessary orientation to Nature that is of interest here. Thus the concept of the cosmos being modelled in the human form is not in itself the significant difference from Western European science, but the analogy lead to a belief that the proper orientation for understanding the cosmos was to contemplate the human form. This attitude is strikingly similar to attitudes that have gained favour in western cultures since the 1960’s, such as the Gaia hypothesis that interprets the earth as a kind of superorganism (Yearly 1995, p. 459).

The Taoists’ beliefs

The third group, the Taoists, sought to find the order of the cosmos by communing with Nature, rather than by reflecting on social life as did the Confucians. Like the Confucians, however, the Taoists valued intuition, though not to the same extent. For the Taoists, nature was ‘conceived as the continual interplay of pairs of opposite forces and qualities’ such as gravity and lightness, stillness and movement, softness and hardness, weakness and strength, which, notes Jaki, are paradoxical and unpredictable:

Nature for Taoism is an all-encompassing living entity animated by impersonal volitions ... As a result Nature could not be expected to yield her [sic] secrets to analytical reasoning or to systematic research activity. (Jaki 1974, pp. 28-9)

The proper orientation to Nature was rather to respond to the ebb and flow of the Yin and Yang. In this way the ‘intimate, organic unity’ of the individual with Nature would be least disturbed. Note again the similarities not only to the Aztec and Indian beliefs, but also to the holistic and organistic beliefs that have resurged in western cultures in recent decades, in opposition to the reductionist and positivistic beliefs that dominated metascientific thinking for the first half of the twentieth century. Of this, more later.

The effect of beliefs on Chinese natural philosophies

It remains to examine particular beliefs held by the Chinese, or outcomes of them, and suggest their effect on Chinese science or natural philosophy. The first is the general beliefs about the cosmos or metaphysical system, the available concepts provided by this world view, and beliefs about their proper use. The Confucian conception of an organistic cosmos in human form, discussed above, is an example. An attendant belief was that understanding of the cosmos was to be gained by contemplation of the human form.
Jaki’s characterisation of differences between Chinese and Western European natural philosophies

Jaki advances a further five reasons for the difference between science in China and in Europe, all of which relate to underlying beliefs and attitudes. The first is the lack of impact of empirical knowledge - observational data - on the broader world view or cosmology in China prior to the seventeenth century. Thus, for example, the Chinese had developed extensive astronomical data (such as the recording of each sighting of Halley’s comet for over two thousand years). But this had no impact on the organistic (animistic) and cyclic view of nature. So the periodic movements of the sun, moon and planets were interpreted as ‘something analogous to the behaviour of animals that go in and out of their hiding places’ (Jaki 1974, p. 33). Jaki argues that this approach results from an attitude that is reflective and responsive rather than inquisitive. The present thesis interprets this as the observational activities having no impact on the belief system, and there being no unified world view.

The second reason stems from the cyclic world view: the Chinese conception of causal connections between events. The view that everything has a cyclic nature did not lead to western view of cause and effect, since the order of interpretation of events could even be reversed. This contrasts with the western view of causes followed by effects, with a third class of coincidental events not causally related. A striking example given by Jaki demonstrates the effect of the different beliefs concerning cause, effect and time:

[T]he Chinese saw nothing inordinate in attributing the political failure of a certain prince to the sacrificing of humans at his burial.

... In such an outlook, measurable, quantitative aspects of events occurring closely in time could have no particular significance. Their frequency or order of magnitude commanded no special interest, nor did the normal sequence of events. (Jaki 1974, p. 34)

It is difficult to conceive of people not learning by induction, at least in the sense of everyday understandings. However, this example points clearly to a different notion of cause and effect that mitigated against learning inductively from experience in at least some contexts. We have noted, for example, that the Europeans had persisted with the Aristotelian belief that the terrestrial and celestial realms were governed by different physics, a belief that prevented a unified view of the world. It is quite possible, therefore, that other belief systems also precluded a unified view of the world. Certainly Jaki’s example implies that the relationship of explanations and predictions to observational data was not clear. In turn, this may be attributed to an underlying belief concerning the reliability or predictability of Nature: regularities were not expected.

Thirdly, Jaki argues that there was an unconfident attitude in investigating Nature, a ‘despondency about man’s [sic] ability to decipher the exact patterns of nature’ which he attributes to this world-view and the attendant attitudes of introspection and ‘self-
Appendix B.2: Belief system

centredness’ (Jaki 1974, p. 35). This air of resignation and defeat is found even in the writings of the prominent sixteenth century thinker Wang Yang-Ming who describes himself and a friend as becoming mentally exhausted trying to fathom the principles of the structure of bamboo. He concludes:

‘... I knew there was really no one who could investigate the things under heaven. The task of investigating things can only be carried out in and with reference to one’s body and mind.’ (quoted by Jaki 1974, p.35)

From a Western European scientific perspective one might comment here that there is no belief here that Nature can be understood by a reductionist approach: by examining the parts rather than the whole. In turn, this entails beliefs about metaphysical qualities or categories, which enable some justification for examining the cosmos considered in this way and not that - by examining these metaphysical categories and not those.

Fourthly is an attitude, stronger than resignation or despondency, of resistance to European science. Its effects ranged from a rejection of European-sourced maps, which did not show China as the centre of a (probably) flat Earth, to specific rejection of the methods and underlying attitudes and beliefs of European science. Jaki (1974, pp. 36-9) notes the ‘failure’ of the Jesuits to establish the European scientific tradition in China over more than two hundred years, despite repeated demonstrations of particular successes. Writing in 1799 about Chinese and European mathematics and mathematicians, Juan Yuan concluded:

‘Our ancients sought phenomena and ignored theoretical explanation. Since the arrival of the Europeans, the question has always been concerning explanations, circular orbits, mean movements, eclipses, and squares. The foreigners think the earth revolves about a fixed sun ... but the theory of Tycho has been modified many times during the last century and I believe that it will be again ... Therefore I do not see upon what the Europeans base their arguments ... and really it does not seem to me the least inconvenient to ignore the western theoretical explanations and simply to consider the facts.’ (from L. van Hee, 1926, quoted by Jaki 1974, p. 39)

Interestingly, Juan Yuan does not characterise the identification of the earth with the human form as theorising. This illustrates the difficulty noted above in making judgements about beliefs from within a particular belief system. Also as noted above, however, it serves nonetheless to show the significance of ontological and epistemological beliefs in characterising science.

Finally was the manner in which related concepts were defined and used. The vagueness of the central concept li has already been mentioned. The concepts of Yin and Yang, also mentioned already and probably better known to people in contemporary western cultures, are likewise characterised as vague, but this is only part of their difficulty with respect to science in the Western European tradition. The meanings attached to each changed significantly over time, so that the Yang, which started as meaning bright sunlight, came to represent maleness, hardness and weightlessness, then later still all that is hot, dry and pure, including fire, roundness, movement, peace, eating, wealth, cheerfulness,
celebrity and profit. The *Yin* grew as the opposite of each of these. Also, the interplay between the *Yin* and the *Yang* implied reversals at times, and discussions of phenomena were more poetic than accurate with an aim of reproducibility (Jaki 1974, pp. 44-46). The lack of precision available for conceptualising the cosmos affects not only the language available for describing phenomena, but reveals an underlying belief the cosmos is only to be understood in these imprecise ways. It also implies a belief, once again, Nature is capricious, although the patterns in the meanings attached to the *Yin* and the *Yang* indicate belief in some, albeit imprecise, regularity or order.

In summary, the Aztec, Indian and Chinese examples demonstrate that: (1) different beliefs about the cosmos (ontological beliefs) are associated with different cultures; (2) beliefs about the appropriate way to relate to the cosmos arise with these world views; and (3) these other beliefs and attitudes were not conducive to developing a tradition similar to the Western European scientific tradition. The examples from these cultures exhibit metaphysical, logical, epistemological and linguistic frameworks and resources, against which the metascientific literature contrasts belief systems in the western European scientific tradition. The claim that Thales and the subsequent Ionians and, later, other Greeks, embarked upon a different course can be made partly in terms of belief systems that they developed, but the claim in itself is simplistic. Belief systems are complex, and there have been a number of beliefs held at various stages of the western European scientific tradition that were similar to those held in other cultures. As with other characteristics of science, enduring beliefs have probably persisted because they were fruitful: these include naturalistic ontologies, beliefs in a uniform and (mathematically) regular cosmos, beliefs supporting experimentation, and fruitful metaphors and models. The complex nature of belief systems serves as a caution against simplistic comparisons between different belief systems. As noted in the companion chapter on context, there is a balance to be struck between recognising, on the one hand, the successes of beliefs that have underpinned and guided western European science, and on the other, the fruitfulness of other belief systems, including non-western and earlier European belief systems. To conclude the summary: (4) there is often overlap between different belief systems; (5) there are difficulties in distinguishing belief systems; and (6) belief systems have changed over time, including belief systems that characterise western European science.

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10 The problems with making judgements between cultures was discussed in the companion chapter on context. This thesis supports the post-positivist argument that it would be ethno-centric not to be astonished if non-western cultures developed the same tradition as western cultures. The very identification of belief system as a dimension of characterisation serves to draw our attention to the beliefs, assumptions and attitudes entailed in characterising modern western science and characterising differences from other natural philosophies.
### Table B.2.1

Examples of characterisation of key metascientific viewpoints by belief system

<table>
<thead>
<tr>
<th>Author</th>
<th>Viewpoint</th>
<th>Examples of reference to belief system</th>
<th>Identified in the work of</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suppe 1973, 1979</td>
<td>Received View</td>
<td>Knowledge is given only in experience. Observation can be independent of theory (observation and theory statements are distinct). Theories can be analysed by rational reconstruction. Rational reconstruction concerns only the context of justification, and not the context of discovery (i.e., science concerns justification, not discovery). Laws are true, or approximately true.</td>
<td>Carnap; the Vienna Circle</td>
</tr>
<tr>
<td></td>
<td>sceptical descriptive</td>
<td>Theories can be analysed by how they are actually used, not by their rational reconstruction.</td>
<td>Achinstein, Rapoport</td>
</tr>
<tr>
<td>Weltanschauungen (world view)</td>
<td>Scientific knowledge is not acontextual, but instead is meaningful only within a Weltanschauungen; Laws are neither true nor false: they represent regularities (Toulmin); Science develops incrementally (Toulmin); Science develops discontinuously (Kuhn); Discovery can be understood (Hanson); Knowledge by falsified or verified, never proven true (Popper); There is no characteristic method of science (Feyerabend)</td>
<td>Bohm, Feyerabend, Hanson, Kuhn, Popper, Toulmin</td>
<td></td>
</tr>
<tr>
<td></td>
<td>semantic or model-theory</td>
<td>Scientific knowledge is given in the language of theories.</td>
<td>Beth, Suppe, Suppes, van Fraassen</td>
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<tr>
<td></td>
<td>historical realism</td>
<td>Scientific knowledge arises from the reasoning by which theories are developed as well as from experimental data.</td>
<td>Lakatos, Shapere, Toulmin</td>
</tr>
<tr>
<td>Bhaskar 1983</td>
<td>empiricism</td>
<td>Knowledge of the cosmos is given in experience.</td>
<td>Francis Bacon, Berkeley, Hobbes, Hume, Locke, Mach (positivism), Mill, Russell, Vienna Circle (logical empiricism)</td>
</tr>
<tr>
<td></td>
<td>idealism</td>
<td>Knowledge of the cosmos is what we make or construct.</td>
<td>Berkeley, Fichte, Hegel, Hume, Kant, Plato, Schelling</td>
</tr>
<tr>
<td></td>
<td>realism</td>
<td>Knowledge of the cosmos is given in an external reality, but is constructed. The order discovered in Nature exists independently of people.</td>
<td>Aristotle, Bachelard, Bhaskar, Duhem, Feyerabend, Hanson, Harré, Hesse, Hume, Kant, Koyré, Kuhn, Plato, Popper, Putnam, Quine</td>
</tr>
<tr>
<td>Nussbaum 1989</td>
<td>rationalism</td>
<td>Knowledge can be proven or confirmed; it is mainly acquired by the power of the intellect.</td>
<td>Descartes, Kant, Plato</td>
</tr>
<tr>
<td>Belief System</td>
<td>Description</td>
<td>References</td>
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<tr>
<td>empiricism/positivism</td>
<td>Knowledge can be proven or confirmed; it is mainly acquired by the evidence of the senses.</td>
<td>Bacon, Comte, Hempel, Hume, Locke</td>
<td></td>
</tr>
<tr>
<td>constructivism</td>
<td>Knowledge cannot be proven. The best current knowledge is acquired according to (a) inner disciplinary criteria (rational, logical, empirical) (b) outer disciplinary criteria (social-psychological, historical).</td>
<td>(a) Popper, Lakatos, Toulmin, partly Kuhn (b) Kuhn, Toulmin, partly Lakatos</td>
<td></td>
</tr>
<tr>
<td>Boyd, Gaspar and Trout 1991</td>
<td>The definitions of scientific concepts and terms are theory-dependent.</td>
<td>(a) Partly Popper (b) Hanson, Kuhn (c) Boyd, Goodman, Kripke, Putnam, Quine</td>
<td></td>
</tr>
<tr>
<td>Pickering 1992</td>
<td>Scientific culture exists in a field of knowledge and knowledge claims.</td>
<td>As given by Suppe</td>
<td></td>
</tr>
<tr>
<td>scientific knowledge as objective (logical empiricism)</td>
<td>Scientific knowledge arises within various cultural contexts.</td>
<td>Kuhn, Feyerabend</td>
<td></td>
</tr>
<tr>
<td>scientific knowledge as relative to culture</td>
<td>Scientific concepts at different levels of abstraction are linked together by generalisations and to the natural world by instances grouped under observation terms. 'New scientific knowledge entails seeing new situations as being relevantly like old ones.' (p. 4)</td>
<td>Barnes, Bloor, Callon, Cartwright, Collins, Garfinkel, Gilbert, Knorr Cetina, Latour, Law, Lynch, Mulkay, Shapin, Woolgar</td>
<td></td>
</tr>
<tr>
<td>Callon 1995</td>
<td>The cognitive or disciplinary organisation of science arises from scientific statements, and constrains the social organisation of science. Model 2 applies here.</td>
<td>Hesse, Holton, Popper</td>
<td></td>
</tr>
<tr>
<td>science as rational knowledge</td>
<td>The cognitive/disciplinary organisation of science is encouraged by the social organisation of science (internally); external boundaries are clear, beyond which scientific structures break down.</td>
<td>Althusser, Ben-Cole, David, Freudenthal, Hull, Merton, Popper</td>
<td></td>
</tr>
<tr>
<td>science as competitive enterprise</td>
<td>Organisation and institutional forms are only moderately significant; more significant are social structures, such as master-disciple relationships. Boundaries are constructed by actors.</td>
<td>Bachelard, Barnes, Collins, Fleck, Knorr, Kuhn, Mulkay, Pinch, Ravetz, Rudwick, Schaffer, Wise, Wittgenstein</td>
<td></td>
</tr>
<tr>
<td>science as sociocultural practice</td>
<td>There are two perspectives on organisation: (1) the overall dynamics of networks of actants; (2) the internal management of the elements of networks.</td>
<td>Amaan, Callon, Foucault, Knorr Cetina, Latour, Pickering, Wise, Woolgar</td>
<td></td>
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</tbody>
</table>
Appendix B.3

Argument from the metascientific literature emphasising the dimension purpose

Debates in the metascientific literature address many aspects of purpose in science, which again support a broad interpretation of scientific purpose. This scope is indicated by the review of the following metascientific arguments in Appendix B.3:

- B.3.1 Current metascientific views with respect to purpose;
- B.3.2 The role of purpose in characterising a western European scientific tradition;
- B.3.3 Purpose as seeking
  a) knowledge
  b) solutions to problems
  c) regularities
  d) causes
  e) other ends
- B.3.4 Control of Nature as a purpose of science
- B.3.5 The strengthening of utilitarian purposes in the twentieth century
- B.3.6 Critical perspectives on scientific purposes

3.1 Current metascientific views with respect to purpose

While analysis of text units from the summary statements indicates that science is characterised by purpose, more complex and sometimes subtle notions of purpose are embedded in metascientific argument in the literature. More particularly, there are different notions of scientific purpose, and these are useful in characterising different views of science. The six metascientific analyses in Table B.3.1 indicate some of the main metascientific approaches in the literature. Each provides a categorisation of viewpoints: the categories within each represent the variety of viewpoints identified by the author, and the differences between them underscore the differences between analyses of metascientific viewpoints. The categories are not discrete, and clearly more than one label can represent many individual thinkers. The present paper interprets each viewpoint as a complex of characteristics, of which purpose is but one. Table B.3.1 highlights the purposes constituted in each viewpoint, to help discern similarities and differences between metascientific accounts, and to show the use of purpose in characterising science.
As a general statement, all views characterise science as having a purpose or goal of generating knowledge about the cosmos: activities are carried out and structures are made to this end, whether implicitly or explicitly, and whether directly or indirectly\(^1\). Some views, having tacitly accepted the creation of knowledge as general purpose, focus on how or why this is done, or on other purposes. Some of these foci and additional purposes do not enjoy consensus and are sometimes disputed; the present section will present some examples of how scientific purpose is characterised in the literature.

The three broad views that comprise the post-positivist consensus within HPS - constructivism, post-positivist empiricism and scientific realism - can be partly characterised by purpose. HPS views primarily characterise science by knowledge, and thus typically the purpose of scientific activities and structures is to develop this knowledge. Typical subsidiary goals are to predict and explain.

In (a) constructivism or neo-Kantianism, as given by Boyd, Gasper and Trout (eds 1991) and Bhaskar (1983k), the purpose is \textit{to construct knowledge} socially or mentally, such that it conforms to psychological structures, a \textit{Weltanschauungen}, or other contextual factors.

In (b) empiricism, the purpose is \textit{to generate certain knowledge of the cosmos}, where its certainty is guaranteed by conformity to methodological and logical rules. Francis Bacon’s empiricist goal of controlling Nature follows from this assumption of certainty.

In (c) scientific realism as given in Bhaskar (1983k), the purpose is \textit{to construct knowledge of an external reality}, by cognitive and social means.

Within STS, Gallon’s (1995) four models of scientific development also indicate a general acceptance of a goal of developing knowledge about the cosmos. However, this goal is sometimes assumed, implied or receives only passing mention: the generally critical tenor of STS approaches means that they commonly interpret such a goal in terms of functional, ideological and other goals.

Thus, where science is characterised as (a) rational knowledge, a characteristic purpose is \textit{to generate statements of codified knowledge} by which this rationality can be demonstrated.

Where science is characterised as (b) a competitive enterprise, a characteristic purpose is not only \textit{to generate statements} but \textit{to test or scrutinise them against competing statements}.

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\(^{1}\) See the respective dedicated companion chapters on activity and structure and Appendix B; the present chapter addresses them to the extent they are characterised by purpose. The reader is reminded that the separation of these categories of characterisation into the companion chapters is an analytical device of the present thesis, and that the six are proposed as an interactive set, not as individual alternatives.
Where science is characterised as (c) sociocultural practice, characteristic purposes are to achieve a variety of cognitive and sociocultural ends:

To account for the dynamics of scientific activity, there is no need to invent new sociological explanations. Barnes (in *Interests and the Growth of Knowledge*, 1977) provides the clearest and most systematic presentation of this point of view. Inspired by the Marxist tradition, of which we may also find traces in Habermas’s work, he writes: “Knowledge grows under the impulse of two great interests - an overt interest in prediction, manipulation and control, an overt interest in rationalisation and persuasion” (p. 38). Thus, in the phrenological controversy studied by Shapin (1979), we find a mixture of sociopolitical and cognitive interests. The endeavour to clarify the possible existence of the frontal sinuses is as much to score points in the class struggle in Edinburgh as to learn anything about the brain. These two families of interests are to be found in all societies; if certain ones like our own have developed science, it is for contingent historical reasons. Interests linked to prediction and control have been intensified and then inscribed in specific institutions.

More generally in [sociocultural models], the explanation of the underlying scientific dynamics depends on the particular sociological models used. We have just evoked Barnes’s macrosociology but there are microsociological possibilities. In Pickering’s recent texts, we find an explanation that makes no distinction between a scientist and any other goal-oriented social actor: ‘Doing science is real work’ (Pickering 1990). Science is a practice and is analysed like all practices; a researcher has resources, tries to reach her [sic] goals, and seeks to create coherence between the disparate and sometimes intractable elements that make up her environment (instruments, theoretical, and experimental models), some of which resist all reorganisation. (Callon 1995, p. 45)

Here, Callon appeals to examples - from Barnes, Shapin and Pickering - that exemplify characterisations by context, but note that particular and various intentions, purposes or aims arise from particular and various contexts. Thus we interpret Barnes’s notion of knowledge growing under the impulse of two great interests to mean that scientists develop knowledge to meet two main sets of interests or goals: on the one hand, to gain or increase scientific prediction, manipulation and control, and on the other hand to achieve rationalisation and persuasion. These two aims align with Shapin’s identification of cognitive and sociopolitical aims. Pickering’s notion of science as work explicitly entails goals as for any work: work is purposive activity.

Where science is characterised as (d) extended translation, a characteristic purpose is to establish coherence between actants (technical devices, statements and human beings) because, in these characterisations, meaningful statements about the world depend on this coherence.
3.2 The role of purpose in characterising a western European scientific tradition

Historical accounts of science partly characterise the western European scientific tradition by scientific purposes. While a broader survey of this tradition is given in Appendix B.1, as part of the discussion of historical contexts, the present section will draw on the literature to illustrate the development of purpose in characterising an historical tradition. This will comprise examples from antiquity, the Scientific Revolution, and developments leading into the twentieth century. Scientific purpose in the twentieth century merits particular discussion, and is addressed further, in section 3.5 below.

We have noted earlier that the western European scientific tradition is generally characterised as beginning with the Ionian naturalists, a characterisation drawing on purpose as much as on any of the other dimensions. Thus part of the metascientific interest in Thales and the Ionians is 'the naturalist aim of explaining the observed variety of natural processes by means of deterministic laws about the basic underlying matter' that is traced through to Democritus and others (Irwin 1989, p. 50). In rejecting Homer's appeal to authority and tradition, the ancient naturalists sought to develop an account based on an interplay of reason, observation and phenomena:

Heraclitus raises some of the right questions in the theory of knowledge (epistemology; Greek *episteme*, 'knowledge'). He rejects the traditional appeal to the Muses, and does not want to be accepted as an authority. 'Don't listen to me', he says, 'but to the *logos*.' Grasp of the *logos* ('reason', 'account', 'argument' are all aspects of the meaning) is not the mere accumulation of information. Heraclitus criticises excessive trust in the senses: 'The eyes and ears of those who have the souls of barbarians are bad witnesses for human beings'. Unquestioning confidence in the senses is like children's trust in what their parents tell them, reflecting failure to make deeper inquiry. (Irwin 1989, pp. 33-4)

That is, Heraclitus argued a particular purpose of inquiry: naturalistic inquiry should aim for a reasoned explanation of observations, not the mere accumulation of observational information. While Heraclitus differed from some of his contemporaries in the relative emphasis he placed on observation and other activities, we recognise that these activities represent different attempts to achieve the same, underlying, goal. Similarly down through history we identify activities as scientific partly by their intention or purpose. We noted in the preceding section that all current metascientific views presuppose some basic aim of acquiring reliable knowledge of the cosmos, and we can add that this basic aim can be traced throughout the history of science. The different approaches to this aim, and others, help to fill in the picture.

Socrates and Plato pursued different aims, respectively ethics and metaphysics, from those of the early naturalists, and partly because of this their work is considered usually less scientific than that of the Ionians before them or of Aristotle afterwards. Aristotle sought to reconcile the earlier tradition of studying Nature with the dialectical
Appendix B.3: Purpose

approach derived from Plato (Irwin 1989, p. 118). The historical domination of Aristotelian science meant that Aristotle’s notion of purpose in natural philosophy had considerable historical influence on conceptions of scientific purpose, and still influences current conceptions of scientific purpose. Aristotle is significant to the present discussion of scientific purpose in two ways, because we discern in his account two senses of the term purpose: (a) in the sense of the *purpose or aim of natural philosophy* (or science), and (b) in the sense that Aristotle’s complex system of natural philosophy includes the notion of *ontological purpose*, or the ends to which natural things develop. The two are related. In (a), the aim of Aristotle’s natural philosophy was to search for the causes of things (Oldroyd 1989, p. 30), according to his schema of *four causes*. In a technical sense this aim is to seek the answer to the question *Why?*, ‘about some entity or event in our experience’, for which there are four standard answers as explanations. One of the four answers or causes is (b), an explanation in terms of purpose in Nature. An example of a standard account of Aristotelian causes is Mason’s summary:

Aristotle, like Plato, considered that intellectual designs and purposes were the formative and guiding principles of all natural processes. However, Aristotle had a richer view of causality than Plato as he accepted also some of the doctrines expressed earlier upon the matter. There were, Aristotle indicated, four main types of cause ... (Mason 1962, p. 43; emphases added)

Thus the purpose of Aristotelian scientific inquiry was to inquire: What Matter is involved? What Form is Involved? What was responsible for there being this phenomenon to investigate? and What End was sought? A scientific explanation was made when these four questions could be answered, that is, Material, Formal, Efficient and Final Causes could be given to account respectively for the matter, form, mode and direction of change. More recent analyses point out that Aristotle’s schema has been misrepresented often as being teleological, because he valued the causes that referred to ends (*tele*, final causes) as the most important (Tiles and Tiles 1993, p. 96). This is the basis for crude comparisons between Aristotelian and modern science based on purpose:

This has traditionally and rather misleadingly been called Aristotle’s *Theory of the Four Causes*. It is often said that Aristotelians sought four causes: a Material Cause, a Formal Cause, an Efficient Cause, and a Final Cause. It is then usually remarked that modern science has reduced this fourfold quest to one since it is said we nowadays recognise only the efficient cause. This is, at best, a half truth ... (Harré 1985, p. 126)

Thus characterisations of Aristotelian purpose, particularly in comparisons with modern science, are sometimes flawed: to characterise Aristotelian science as simply teleological is wrong in omitting reference to all four; to attribute modern meanings of *cause* to the Aristotelian notion of answering four types of question is imprecise; and to characterise the difference between Aristotelian and modern science as a reduction of the four
Aristotelian causes to one (or two), is 'a half truth' because in modern science embryology, at least, uses teleological explanations\(^2\).

The developments that characterised the Scientific Revolution, such as the demise of the Aristotelian system, also include notions of purpose. Bronowski has argued that the Scientific Revolution is significant because it marks a fundamental change between 'an old way of thinking and a new way of thinking' (Bronowski 1978, p. 4). The 'new way' is characterised by the goal of constructing a single, unitary system of knowledge of the world, and which, according to Bronowski, has not been achieved outside science:

We are faced with having to try to build a unitary theory of the world - one which involves all human life and yet is conceived in the scientific discipline which, in my view, has transformed the world since 1600, plus or minus a hundred years. In my view, this is a unique endeavour. There has never before been a moment in history when there has been an attempt to see the world as a whole and from a single core or type of explanation. (Bronowski 1978, pp. 5-6)

That is, the aim of explaining the world by a unitary system of knowledge is central to Bronowski's characterisation of science after about 1600, and the criterion by which he delineates that science from all other human endeavours from that time onwards. The present thesis interprets this as a difference in purpose.

The investigative tradition following the Scientific Revolution is characterised by the development of several notions, aspects or 'levels' of scientific purpose. (These variations of purpose are pursued below in sections 3.3 and 3.4). For example, Francis Bacon seems to have accepted and developed Aristotle's goal of searching for causes:

Bacon, like Aristotle, believed that the search for causes was the proper role for the scientific investigator. (Oldroyd 1989, p. 30)

However, the aim of identifying teleological causes was challenged. Aristotelian ontological purpose - the metaphysical belief that Nature tended to develop towards unrealised perfect forms or teleologically - came under attack from several quarters, including Francis Bacon, who realised that an explanation of causality as a tendency towards that effect is no explanation at all (Collingwood 1945, p. 93). The need for teleological explanations disappeared as different beliefs emerged of how Nature changes: the Aristotelian assumptions about organicist development in Nature were replaced, notably during the sixteenth century, with different assumptions that Nature has intrinsic and mechanical causes (Collingwood 1945, p. 94). The more immediate purpose of Bacon's experimental, inductive and qualitative approach was to generate axioms, hypotheses and theories of wide generality, for the higher purpose of collecting reliable knowledge of the cosmos. In turn, the higher purpose of seeking this knowledge was Bacon's celebrated notion of control of Nature and equation of knowledge with power through the control of Nature:

\(^2\) Some systems, or complexes of events, like embryonic growth, make sense only if interpreted as being directed towards some purpose. (Quinton 1988)
The object of Bacon's science, then, seems to have been the mastery of nature by the discovery of forms. (Oldroyd 1989, p. 63)

Oldroyd notes that Bacon used the word form to mean something like a law of Nature, which described the appearance of a 'nature', and was thus taken as its causal explanation. The interrelatedness of knowledge, causes and laws as goals is taken up in section 3.3 below. The view of scientific purpose as seeking control over Nature has been very influential and is elaborated in section 3.4 below.

Bacon's characterisation of science, including scientific purpose, was very influential in seventeenth century England, eighteenth century France, and the nineteenth century work on evolutionary biology and geology (Mason 1962, pp. 141ff). Thus Robert Hooke (1635-1702), who is noted for his scientific successes, 'was one of the first secretaries of the Royal Societies of London, and some of the early members of that organisation specifically set out to perform scientific investigations in the manner recommended by Bacon' (Oldroyd 1989, p. 66). However scientific progress in the seventeenth century mostly came from the mathematical-deductive approach of Galileo and Descartes. Now, while Descartes 'had read Bacon's views on scientific method and sympathised with his aims', his purpose was to seek out the laws that he believed controlled Nature (Mason 1962, pp. 166ff).

In the development of metascientific views following the evident successes of science from the Scientific Revolution, the purpose(s) of science underpinned much argument. For example, Newton sought to develop general explanatory laws, as did Descartes, but unlike Descartes he emphasised the role of experimental evidence as their basis. Thus Newton's Method of Analysis, and his Synthesis and Axiomatic Method, 'share as a common objective the explanation and prediction of phenomena' (Lossee 1980, p. 90). Newton's belief that scientific laws are contingent and revisable meant that, on his account, necessary knowledge could not be a goal of science:

Newton repudiated the Cartesian program of deducing scientific laws from indubitable metaphysical principles. And he denied that a necessary knowledge of scientific laws can be achieved in any manner. According to Newton, the natural philosopher may establish that phenomena are related in a certain way, but cannot establish that the relation could be otherwise.

It is true that Newton did suggest that if we could know the forces that operate on the minute particles of matter, we could understand why macroscopic processes occur in the ways that they do. But Newton did not maintain that such knowledge would constitute a necessary knowledge of Nature. On the contrary, he held that all interpretations of natural processes are contingent and subject to revision in the light of further evidence. (Lossee 1980, pp. 93-4)

As noted in Appendix B.2, Newton's notion that science knowledge is revisable seems to have been insufficiently acknowledged by the positivist RV, and given due recognition in post-positivist metascience.
Like Newton and Locke, David Hume (1711-76) was sceptical about the possibility of necessary knowledge of Nature (Lossee 1980, p. 101). He argued that what we believe to be a causal relation is nothing more than a mental inference about the constant conjunction of sequential events. This is a different notion of causal explanation to those of Aristotle and Bacon, and has been a very influential view. In response, Kant (1724-1804) considered Hume to have missed a significant characteristic of science, the goal of systematic knowledge of Nature:

Kant believed that Hume was preoccupied with inductive generalisation. Kant held that this emphasis draws attention from the most important feature of science - the attempt to achieve a systematic organisation of knowledge ... Kant regarded the systematic organisation of experience as a goal to be sought by the knowing subject. (Lossee 1980, p. 108)

On the other hand, John Mill (1806-73) endorsed the goal of seeking causal explanations, but refined it to allow invariable sequences to be causal, like vigorous bubbling when sodium is added to water, or non-causal, like night following day (Lossee 1980, p. 155). As metascientific thinking developed, purposes were related also to what are now regarded as constructs, such as laws and theories. Thus Norman Campbell (1880-1949) argued that 'the aim of science is the discovery and explanation of laws', where laws are explained only as they are incorporated in theories (Lossee 1980, p. 139). For Henri Poincaré (1854-1912), laws such as Newton’s laws of motion are means to higher goals, serving both as conventions that define scientific concepts, and as empirical generalisations (Lossee 1980, p. 168).

The positivist RV and variants of it provided a normative prescription of purpose which was very influential for much of twentieth century HPS, and remains influential in some fields of science and in public perceptions. Positivism is taken usually as a strict form of empiricism (Brown 1977, p. 21). Thus we may take a goal of general empiricism, as given by a line of British philosophers beginning with Francis Bacon, to be the formation of knowledge based on sense experience or introspection (Bhaskar 1983b, p. 121). Positivism holds that the goal of genuine knowledge can be reached only through sense experience (Brown 1977, p. 21). More specifically, positivism as given by August Comte (1798-1857) is the view that valid knowledge can only be gained by the ‘description of the coexistence and succession’ of phenomena that are ‘real, useful, certain, precise, organic and relative’ (Bhaskar 1983i, p. 333). Comte’s idea that sciences develop through three stages characterises the development of sciences by changes in purpose: the initial theological and later metaphysical stages comprise ‘the search for inner natures and essential causes’ whereas the final positive stage comprises the search for ‘the invariant show of phenomena’ (Bhaskar 1983i, p. 334). The invariant succession of phenomena were interpreted as natural laws, and the search for these laws was a notable aim of science in the nineteenth and into the twentieth centuries by empiricists or
positivists such as Comte, John Herschel (1792-1871), Mill and Ernst Mach (1838-1916) (McMullin 1990, pp. 832-5).
3.3 Purpose as seeking solutions to problems, knowledge, regularities and causes

While the preceding section highlighted historical notions of scientific purpose, it should be emphasised that most accounts appeal to more than one notion of purpose. For example, we noted above several notions of purpose in the work of Francis Bacon: as a search for axioms, laws or theories as expressions of pattern or regularity in phenomena; as a search for knowledge of Nature; as a search for the causes of natural phenomena; and for gaining control over Nature. This does not reflect changes of mind by Bacon, but rather, according to a prevailing view in philosophy, that 'questions of causation, inductive support, laws of nature, and counterfactual conditionals\(^3\) are bound closely together' (Sanford 1995, p. 83). Thus the different purposes identified by Bacon, and subsequently highlighted variously in different metascientific accounts, can be taken as reflecting different emphases of a complex notion.

There is, too, a sense in which each of the goals addressed in the present section - acquisition of knowledge, problem-solving, identifying regularities (laws) and identifying causes - can be regarded as just the acquisition of knowledge. However, this fails to reflect both different purposes of knowledge, and the different foci found in metascientific accounts. Accordingly, the present section sets out several of these notions of purpose to show this variation, but with the understanding that they are presented separately simply to reflect the different emphases or perspectives given in different accounts. Causes, inductive generalisations and laws of Nature, are widely held to be related, as noted above, and in any event comprise the knowledge that is also given as a goal. As a result, usually more than one are found in combination in any one account. The purpose of gaining control over Nature is addressed separately in section 3.4 below, because it is not part of this complex notion of purpose, and because it has particular significance in characterising applied science.

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\(^3\) Counterfactual conditionals are 'if-then statements about what would have happened if something else had occurred', as in, 'If a had not happened then b would not have occurred' (Sanford 1995, p. 82).
Appendix B.3: Purpose

a) Acquisition of knowledge as an aim

Many metascientific accounts emphasise the goal of acquiring (discovering or constructing) knowledge. The acquisition of knowledge seems to be included as a goal in most accounts, even if it is implied or presumed in accounts that emphasise other goals; as we have noted, identifying the solutions to problems, or regularities, or causes, which are all given as goals, constitute knowledge and can be regarded as variants of that goal. Acquisition of knowledge is measured frequently as publication in science journals, texts and reports. The acquisition of knowledge was a central goal from antiquity - we have noted it in the work of the Ionians and Aristotle, for example - and it remained central in the vigorous metascientific debates from the Scientific Revolution onwards. While knowledge was an aim of both empiricist and idealist traditions, the former saw it achieved through the intermediate aim of collecting observational data of phenomena while the latter required the intermediate aim of analysing mental activities. The present thesis explores various notions of knowledge in the companion chapter on knowledge and Appendix B.6.

b) Problem-solving as an aim

We have noted above that Popper (1956) acknowledged, almost in passing, that individual scientists have their own aims as they do their work. This very pragmatic notion of purpose should not be overlooked: it is clear that, whether or not an individual scientist is concerned day-by-day with theorising or debates about causation, she or he routinely addresses numerous problems of greater or lesser significance. Individual goals of problem-solving are clearly evident in the great burst of experimental activity that marked the Scientific Revolution, and in subsequent scientific activity down to the present. It is the individual goals, mentioned by Popper, above, to which individual scientists work by identifying problems of natural inquiry and seek to solve them. This corresponds with the day-to-day goal of problem-solving that Kuhn later described (1959) as the routine aim of normal science working within an existing paradigm. Increasingly, these individual goals have been shared by the members of a research team, but that does not affect their nature, which also increasingly, concerns solving problems or puzzles. Moreover, problem-solving is usually presumed in discussions of other goals, as given below.
c) Identifying regularities as an aim

The third purpose of science, identified in the work of Bacon and others, is to *identify regularities or patterns of order in Nature*. These regularities are expressed as axioms, laws or theories. Until relatively recently, this process was almost universally described as *discovering* laws, arising from the belief that natural laws were part of an external reality. Some current, post-positivist accounts now describe the process as *constructing* laws, arising from the different belief that laws, axioms and theories are mental constructions or interpretations of regular phenomena. This belief arose in turn from the realisation that laws, theories and such are not immutable truths but are changed and even rejected as we develop better explanations. In this sense, this aim has changed, from *discovering* to *constructing*, but in a broader sense the aim of *identifying* such regularities - whether by discovering, constructing or some other activity - remains. Thus science is able to describe and/or explain economically a large amount of empirical data, given in observation statements, by means of a small number of general statements, given in theoretical statements or mathematical axioms. The characteristics of laws, theories and axioms are discussed in the companion chapter on structure and Appendix B.4.

This search for lawlike regularities is evident particularly in empiricist and positivist characterisations of science, as in the following examples. Comte's positivism characterised science as maturing through three stages which in turn are characterised partly by changes in purpose:

Comte claims that each science goes through three stages, the theological, the metaphysical and finally the 'positive' where the vain search for absolute knowledge is abandoned, and energies turned to the only achievable scientific goal which is the discovery of empirical laws, 'relations of succession and resemblance'. What characterises the 'positive spirit' is the search for such laws in every domain of nature; though the methods of the different natural sciences are irreducibly different and there are complicated patterns of interdependence between them, they have in common a stress on exact prediction, which is both the test and the practical outcome of the discovery of law. This is true in the social domain just as much as in the natural, though the laws are much harder to establish there. (McMullin 1990, p. 832)

Other examples show some variation in the conception of the nature and purpose of this goal and of the laws themselves. Thus John Herschel (1792-1871) characterised science as seeking lawlikeness as correlations:

Science [for John Herschel] is a search for lawlikeness in nature; the goal of induction is to discover the causal relations, or invariable correlations, between phenomena. (McMullin 1990, p. 833)

John Mill (1806-73) sought both those sequences that were invariable and those that held only in certain circumstances:

Mill distinguishes between 'empirical laws', regularities which hold only under limited circumstances, and 'basic laws of nature', absolutely invariable sequences. The aim of science is to determine the basic laws and to deduce the
empirical laws from them, showing why these take the form they do under the limitations specified. (McMullin 1990, p. 834)

Ernst Mach (1838-1916) saw the formulation of laws as a means to higher goals:

The aim of science [for Ernst Mach] is to formulate 'laws', that is, economical descriptions of sensations, enabling more effective prediction and communication. (McMullin 1990, p. 835)

The development of laws remains a goal of science in contemporary characterisations, even if the notion of laws changed over time. While in general laws are no longer characterised as truths, they remain goals of science because they state the best, current, economical generalisation of regularities of phenomena:

Physics develops the taxonomy of its subject matter which best suits its purposes: the formulation of exceptionless laws which are basic in ... several senses ... But this is not the only taxonomy which may be required if the purposes of science in general are to be served: eg., if we are to state such true, counterfactual supporting generalisations as there are to state. (Fodor 1991, p. 440)

d) Identifying causes as an aim

The fourth purpose of science is to identify the causes of phenomena. Aristotle, Francis Bacon and David Hume, among others, saw identifying causes as a scientific purpose4, and in section 3.2 above we traced some historical examples of seeking causes as scientific purposes. Hume's characterisation of cause as an interpretation of conjoint events, and responses to his view, have dominated discussion of cause down to the present. This debate remains unresolved, and there are several current views (Sanford 1995, p. 79). For example, two majority5 views of causation that arise from Hume are that we cannot directly perceive causal relations, and that seeking causes equates with discerning patterns of phenomena, and hence laws. Conversely, the belief that a cause is earlier than its effect, while popular in general Western culture, is a controversial view in philosophy because it has theoretical drawbacks and critiques from physics.

Another view, prevailing in philosophy, is that causes and effects are events. This view is an example of how an argument for cause, constructed and critiqued in physics, has implications for scientific purpose. This commonsense view of cause and effect equates with that of classical physics, but not with that of quantum physics. Madden (1983, pp. 54-6) has argued that in ordinary life and in classical science, the philosophical interpretation of cause is generally taken to be an event plus a particular or entity, which together lead to an effect, which is another event. That is, the effect event is explained in terms of the causal event and the characteristics of the particular. For example, we might explain the effect event of a can collapsing as follows:

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4 See Appendix B.2 on belief system.
5 Majority, as used here by Sanford, means supported by a majority of metascientists.
The causal event + the characteristic of the particular causes the effect event. 

(pumping the air (the weight) (the surrounding air) out of the can) collapses)

On this view, to seek the cause is to identify the mechanism of the causal event and the identity and characteristics of the particular: that is, the purpose of science is to identify these components of the process. However, an implication of this view is that, just as the effect event requires explanation, the causal event also requires explanation and so cannot itself form part of the ultimate explanation, while the characteristic of the particular is unchanging and so requires no explanation. The solution to these difficulties is not agreed, although achieving or constructing an explanation must remain at least part of the purpose.

The question of causality in quantum physics presents different difficulties because, as discussed in Appendix B.2, it is not justified by our ‘commonsense’ belief in continuity:

The Copenhagen interpretation of quantum events rejects both the notion that all changes require explanation and that particles [are continuous]. Discontinuous action, annihilation of elementary particles, and the radioactive decay of nuclei are all taken as basic and needing no explanation, when in fact such changes and violations of spatial indifferences are precisely what ordinarily and in all other areas of science would require explanation. (Madden 1983, p. 55)

Sometimes this is thought to be resolved by allowing quantum mechanics to apply only at microscopic levels, but questions remain unanswered about how the microscopic and macroscopic are related, and indeed when and how to draw the boundary between the two. Thus, following this notion of causation, in classical physics the aim of identifying the cause is to identify the causal event and the characteristics of the particular, but these are problematic, whereas in quantum physics similar types of causal events are taken as needing no explanation! The reader is reminded here of the discussion, in Appendix B.2, of the occult virtues, characteristic of Aristotelian science, being qualities that needed no further explanation. This has implications for the public understanding of science, which we will discuss in the concluding chapter. Study of the public understanding of science highlights as one of many issues the acceptance or not of ‘scientific’ explanations by the general public, who are often called upon to accept scientific explanations without meaningful understanding. This can be worryingly like occult virtues - a label without an explanation.

e) Other notions of aim

Various accounts argue other aims or purposes of science, and it is worthwhile to note briefly a couple of these. An interesting historical example is the change, in the Scientific Revolution, from seeking to describe Nature to seeking to represent reality. This is noted frequently in the literature as a change in the interpretation of the
Appendix B.3: Purpose

significance of the mathematical procedures. The Aristotelian and Ptolemaic approaches of the Middle Ages, which were sanctioned by the Roman Catholic church, had been interpreted as being functional descriptions but not representing reality. This was called *saving the phenomena*, as discussed in Appendix B.2 on belief system.

Turning to contemporary characterisations, the mixture of post-positivist accounts of science vary in their notions of scientific purpose, as they do with other characteristics. While again these characterisations centre around the purpose of obtaining reliable knowledge of Nature, it is useful to suggest a distinction between those that are concerned with the intermediary goals by which this knowledge can be obtained, and others for which the goal of reliable knowledge is itself an intermediary goal for some higher purpose. As an example of the former, Stephen Toulmin has argued that science aims to describe and provide understandings of Nature through the intermediate aim of developing and using particular explanatory activities and structures:

Stephen Toulmin’s views on science ... were that the foundation of science is to build up systems of explanatory techniques; a variety of representational devices, including models, diagrams, and theories is employed to describe and reason about phenomena. (Suppe 1979, p. 670)

Examples of the latter include the purposes of control and ideology, whose variation and complexities merit separate discussion; this is given in section 3.4 below.

Finally, the companion chapter on context and Appendix B.1 argue that human contexts comprise one of the ways by which the literature and mass media characterise science. Included in human contexts are personal characteristics, such as ambition and curiosity. These characteristics also contribute to scientific purpose: that a scientist pursues investigations within a particular field partly due to personal aims arising from interest or ambition.
3.4 Control of Nature as a purpose of science

A pervasive theme in the literature is that science is the means by which humanity gains control of Nature: that through accumulating reliable knowledge of Nature we are better able to explain, manipulate and make ever more reliable predictions about it. Thus knowledge, explanation, manipulation and prediction can be characterised as intermediary goals by which we can achieve the higher goal of control. As noted earlier in section 3.2, Francis Bacon saw controlling Nature as a purpose of science:

Bacon accepted as a moral imperative that man [sic] is to recover the dominion over nature which he lost in the Fall. He repeatedly emphasised that men must control and redirect natural forces so as to improve the quality of life of their fellow human beings. Thus the discovery of Forms is only the proximate goal of scientific inquiry. One must gain knowledge of Forms before one can coerce nature to serve human purposes. But the ultimate goal of scientific inquiry is power over nature. Bacon’s emphasis on the practical application of scientific knowledge stands in marked contrast to Aristotle’s position that knowledge of nature is an end in itself. It is this emphasis on the control of natural forces that most clearly sets apart Bacon’s philosophy from the Aristotelian philosophy he hoped to overthrow. (Lossee 1980, p. 68)

That is, science has a utilitarian purpose, which is identified in developments of science during the Industrial Revolution and especially in twentieth century science. August Comte affirmed prediction for the purpose of power - savoir pour prévoir, prévoir pour pouvoir (literally to know to foresee, to foresee for power) - in proposing his positivist characterisation of science. This notion became highly significant with the rise in influence of positivism. Note, however, he also affirmed the Aristotelian goal of knowledge as its own end:

There can be no doubt that Man’s [sic] history of nature must furnish the only basis of his action upon nature; for it is only by knowing the laws of phenomena, and thus being able to foresee them, that we can, in active life, set them to modify one another for our advantage. Our direct natural power over everything about us is extremely weak, and altogether disproportional to our needs. Whenever we effect anything great it is through a knowledge of natural laws, by which we can set one agent to work upon another - even very weak modifying elements producing a change in the results of a large aggregate of causes. The relation of science to art may be summed up in a brief expression: From Science comes Prevision; from Prevision comes Action.

We must not, however, fall into the error of our time, of regarding Science chiefly as a basis of Art. However great may be the services rendered to Industry by Science, however true may be the saying that Knowledge is Power, we must never forget that the sciences have a higher destination still, and not only higher but more direct - that of satisfying the craving of our understanding to know the laws of phenomena ...

Our business, it is clear, is with theoretical researches, letting alone their practical application altogether. Though we may conceive of a course of study that should unite the generalities of speculation and application, the time is not come for it. (Comte 1855, pp. 39-40)
The first paragraph, above, succinctly characterises science by the goal of controlling Nature through the ability to predict. In the second and third paragraphs, however, Comte cautions that the greater purpose is developing the knowledge for its own sake, setting out the traditional dichotomy between pure and applied sciences. Section 3.5 below argues that, given the increasingly utilitarian approach to science in the twentieth century, Comte’s judgement that the time is not come for uniting theory and application is now judged by many commentators to apply no longer.

Control as an ideological goal

Control as an end or purpose of science is increasingly part of recent metascientific argument. The quote from Callon (1995) earlier in this chapter centred on Barnes’ (1977) identification of prediction, manipulation and control as an end or interest sought in the production of knowledge. Habermas has been very influential in advancing this argument, arguing that control arises from the equation of knowledge with human interests, and rejecting the positivist notion that reason is free of interests or ideology (Alcoff 1992, pp. 78-9). For Habermas, natural science is a knowledge-producing enterprise among other knowledge-producing enterprises, where each is characterised by its own goals or interests:

There are three categories of process of inquiry for which a specific connection between logical-methodological rules and knowledge-constitutive interests can be demonstrated. This demonstration is the task of a critical philosophy of science that escapes the snares of positivism. The approach of the empirical-analytic sciences incorporates a technical cognitive interest; that of the historical-hermeneutic sciences incorporates a practical one; and the approach of critically oriented sciences incorporates the emancipatory cognitive interest that … was at the root of traditional theories. (Habermas 1968, 1971, p. 308; emphases in original)

That is, Habermas identifies different goals, or interests, with different sciences. He explains these goals as follows (Habermas 1968, pp. 308-317). Technical cognitive interest is the interest in ‘technical control over objectified processes’, meaning prediction, manipulation and control of Nature. Practical interest is the interest in ‘the attainment of possible consensus among actors in the framework of a self-understanding derived from tradition’, which entails the goal of understanding other people. Emancipatory interest seeks freedom through the identification of ideology and compulsion:

The systematic sciences of social action, that is economics, sociology, and political science, have the goal, as do the empirical-analytic sciences, of producing nomological [or law-like] knowledge. A critical social science, however, will not remain satisfied with this. It is concerned with going beyond

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Note that Habermas uses the term science to mean body of scholarly knowledge, as interpreted in European contexts, and not to mean merely natural science, as interpreted in Anglo-American contexts. See Machlup (1980) in summary statements 21 and 22.
this goal to determine when theoretical statements grasp invariant regularities of social action as such and when they express ideologically frozen relations of dependence that can in principle be transformed. To the extent that this is the case, the critique of ideology, as well, moreover, as psychoanalysis, take into account that information about lawlike connections sets off a process of reflection in the consciousness of those whom the laws are about. Thus the level of unreflected consciousness, which is one of the initial conditions of such laws, can be transformed. Of course, to this end a critically mediated knowledge of laws cannot through reflection alone render a law inoperative, but it can render it inapplicable. (Habermas 1968, p. 310; emphases in original)

This goal of identifying the ideologies of knowledge claims is achieved through the activity of reflection.

This notion of control needs to be understood within wider contexts of interpretation. Alcoff (1992) identifies Habermas’s view as an example of critical theory, which, along with phenomenology, hermeneutics, post-structuralism and feminism, is one of the five major orientations in twentieth century continental epistemology. This is the French-German approach to epistemology, which is more concerned with the strategic effects of truth claims, and less with truth and knowledge as the representation of reality, as in the Anglo-American tradition. Post-structuralist approaches, although disparate, probably share ‘the belief that knowledge systems are ultimately contingent and connected intrinsically to power relations and to desire’ (Alcoff 1992, p. 79). Thus Derrida rejects the Western notion that knowledge and language are neutral and transparent, arguing that beliefs are not determined by reality but by plural and shifting interplays of textual elements: thus the goal is to persuade. Foucault also rejects the neutrality of rationality, but characterises it more in terms of power: thus the goal is to maximise power. In response to Habermas, Hesse has argued that the goal of control is inseparable from the goal of human self-understanding, because theories of both embody the same view of humanity and are constructed with the same categories, such as functionality, selection and survival (Rouse 1991, p. 50). Thus interpretations within continental epistemology - notably critical theory, hermeneutics, post-structuralism and feminism - characterise science strongly in terms of goals such as power, persuasion and ideology. Critical perspectives of scientific purposes arise from views such as these, and are discussed at greater length below in section 3.6. Unsurprisingly, stronger versions of this approach have drawn criticism from those who characterise science by goals such as rationality and objectivity (see Gross & Levitt 1994).

To conclude, while the goal of control over Nature is widely embraced, there is tension between accounts which see this as part of a central goal concerning power and persuasion, and those which see power and persuasion as external to science. The substantial debate in the literature, between internalist and externalist characterisations, is a central one to the present thesis, and is discussed at some length in Appendix B.1. The present thesis interprets debates such as these as exercises in boundary work that can be clarified by a multidimensional characterisation of science.
3.5 The strengthening of utilitarian purposes in the twentieth century

To appreciate the nature of scientific purpose in the twentieth century, it is worthwhile reviewing the historical relationship between science and technology, which is well documented in the literature. The brief account following draws mainly from Keller (1983d). Most histories trace two traditions dating from Antiquity: *craft*, characterised largely as an empirical activity, and *learning*, particularly as it involved explanatory theories. These traditions were mostly separate from Antiquity, through the Middle Ages, until the Scientific Revolution. For example, although we note from Antiquity the construction of large buildings and irrigation systems, weapons that threw missiles, the water wheel, the screw press and gear transmission, these developments were essentially independent of the concurrent developments in natural philosophy. Thus, although each involved mathematics, none entailed theories about Nature, raw materials and so on. By the late Middle Ages there had been notable developments in techniques and inventions. Common examples include distillation in alchemy, lens grinding for spectacles, instruments for measuring angles in astronomy, the compass, gunpowder and developments in fortifications. Again, mathematics was used in all - for example, Leonardo da Vinci’s inventions can be geometrically analysed - but the theoretical developments that characterised the natural philosophy of the day remained largely separate.

Although Francis Bacon urged that theory and craft practice should learn from each other, so that rational experiment would produce new inventions to increase the control of Nature, practical benefits from experimentation were indirect for a long while (Keller 1983d, p. 413). First, the union of the two was slow: we may trace this process over at least the period from the 1600s to the 1800s. For example, it was Boyle (1627-91) who brought a more scientific approach to the preparation of chemical compounds as compared with that of the alchemists. Yet the first clearly scientific technology is not identified until a new industry, the manufacture of artificial dyestuffs through chemical analysis and synthesis, emerged in Germany in the mid 1800s. Secondly, the union was unclear: as science and invention came together in, for example, the testing and construction of new instruments and the developments of existing industries, it was not clear when theory informed practice and practice informed theory:

It is unclear then how far the application of steam power was scientific technology and how far the work of craftsmen was guided by scientific education, however elementary. (Keller 1983d, p. 413)

Thirdly, the union was piecemeal: different instances, in different fields and in different countries developed at different times. The emergence of new scientific technologies of

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7 See Appendix B.1.
the 1800s, notably in organic chemistry and electricity, is easily identified but it varied in
different countries; the gradual application of theory in existing technologies was less
clear.

In Whig histories a significant factor in most cases of breakthroughs and
developments was the achievement of individuals. These histories characterise the science
of this period as the flowering of the era of great pioneers and polymaths: John Smeaton
(1724-92), James Watt (1736-1819), Antoine Lavoisier (1743-94), Humphry Davy
(1778-1829), Sadi Carnot (1796-1832), James Maxwell (1831-79) and Thomas Edison
(1847-1931) are a few of many well known examples. Thus many of the science-based
industries of the twentieth century were established in the nineteenth centuries, and for
more recent industries such as information technology and genetic engineering, the model
for large scale science-industry collaboration was established.

The significance here of this history is that, as the utilitarian purposes of technology
merged with science, science became characterised increasingly by utilitarian purposes.
Whereas the scientific outcomes of the earlier individuals such Newton and Galileo had
little impact on, and certainly little use to, many people, the work of Pasteur and Maxwell
had wide practical application much quicker:

In part, that means that the intersections of science and production and of science
and society actually became closer. At the dawn of the Industrial revolution,
James Watt did not actually need to know the theory of latent heat to hit upon the
idea of making the steam engine more efficient by introducing a separate
condenser; a hundred years later, by contrast, only a first-rate chemist would
have been able to develop synthetic dyes. But it means something more
significant too that the traditional boundaries between science and industry and
science and its applications began to dissolve; the very introduction of the terms
‘pure science’ and ‘applied science’ paradoxically witness that process. The
development of electricity during the nineteenth century offers a classic instance
of this. Without top-level scientific research by men such as Faraday, the
electrical industry could never have developed; yet all the electricity which the
scientist investigated and utilised was entirely man-made [sic]. In the present
century, the development of plastics and artificial intelligence offers further
instances of how the scientist has become utterly bound up with society
precisely because what he is investigating is no longer ‘Nature’ (‘out there’ as it
were) but the products of previous scientific-technical ingenuity and industry.

As Latour has convincingly argued, this transformation has immeasurably
enlarged the scope of scientific-technical inquiry; but it also sets new problems
for the historian or historical sociologist of science, since the categories
traditionally deployed for understanding the work of a Kepler or a Newton
(notions for example of ‘discovery’) seem patently inappropriate for an adequate
grasp of the modern laboratory or international research network. (Porter 1990,
pp. 44-5)

The quickening application of science, as described by Porter, is a complex matter:
undoubtedly the technologies became more complex and changed more rapidly, but this
does not explain the application of scientific developments. Part of the answer must be
that the emerging industrial technologies increasingly deployed materials and phenomena
that were produced more or less directly by the efforts of scientists, notably electric
current and synthetic chemicals. Thus an increasing number of scientists were working to solve problems that by definition had short-term, utilitarian purposes; this was not the case for the Newtons and Galileos of earlier times.

These utilitarian outcomes are identified as the wide-ranging and practical applications in, and (frequently indistinct) interactions with, industry, commerce, government, the military, community-based groups and government. An early and influential account of this was given by Ravetz:

Science becomes directly involved with society at large when it is applied to the solution of technical problems, involving the production of the means for the performance of a function, or practical problems, involving the achievement of the purposes of individuals or groups of people ... The investigation of practical problems, and their solution through large-scale practical projects, encounters every pitfall of scientific and technical problems, and then some peculiar to itself. Conflicting ideologies and purposes are at the heart of every urgent practical problem; they lack the accepted criteria of quality for their solution; the sciences involved in them are usually immature; and in their execution they are prone to distortion by the natural tendencies of bureaucratic operation. (Ravetz 1971, p. 408)

Ravetz does not argue that the character of science is solely determined by its usefulness, for he does proceed to remind us that, writing in 1971, that 'a large part of scientific research proceeds as before, in a social context which is still mainly 'academic' rather than industrialised' (Ravetz 1971, p. 409). That is, its goals remained largely cognitive. Nonetheless, as he points out, as science is increasingly enmeshed in a wider social context, so too is the value of science increasingly measured by its usefulness to society: the sciences will continue to be supported 'so long as they are considered as performing these functions better than any feasible alternatives' (Ravetz 1971, p. 410).

In the less than three decades from Ravetz's book to the present thesis, a substantial STS field and literature has emerged that has identified and critiqued the multifarious and inextricable links between the goal complexes of the sciences and other social endeavours. This corpus is too substantial to explore here, but an indication of its scope and, by inference, the complexity of an overall characterisation, can be gained by a simple review of the more relevant entries in the review of the STS literature given in Jasanoff et al (eds) (1995). They include the following.

• Studies of engineering identify both internalist goals, for developing the cognitive discipline, and externalist goals, relating to the broader social application of engineering activity, as for metascientific analyses (Downey & Lucena 1995).

• Feminist studies of technology characterise technology as shaped by male rather than female interests or purposes, in much the same way as we identify technology as being shaped by military or capitalist purposes (Wajcman 1995).

• Sociohistorical studies of technology, notably as case studies, provide detailed accounts of the multiple participants in technologies, that inform the balance
between characterisations of technology as deterministic (meeting its own ends) and socially produced (meeting social ends) (Bijker 1995).

- The spreading use of computers rarely creates its own ends by 'causing' direct social change, but does create possibilities and pressures for meeting social ends, notably industrial, military and commercial purposes (Edwards 1995).

- The Human Genome Project promises to reconfigure the nature of biology, medicine and society, though not always in the ways initially envisaged; it arose through an intriguing mix of social and cognitive goals, but as it proceeds debates are opening about the future purposes and ends of the emerging database (Hilgartner 1995).

- Studies of the construction and disputation of scientific boundaries show that characterisations science and non-science arise from the purposes of those constructing the characterisations, where scientists do not always have control over the characterisation of science (Gieryn 1995).

- Studies of science controversies (Nelkin 1995), including public decision making (Martin & Richards 1995) and environmental debates (Yearley 1995), frequently entail boundary disputes, and accordingly also identify in representations of science the goals of those constructing the representations. This is all the more interesting in disputes where not only scientists but political interest groups lose control over the characterisation of science, i.e. of the legitimisation of goals and purposes.

- Different theoretical perspectives on decision making posit different goals, of which Martin & Richards (1995) identify four: superior knowledge (in positivist accounts); superior political/economic/social resources (in studies of group politics); superior persuasiveness/knowledge/politics (in SSK accounts); or the hegemony of the dominant social structure (in studies of social structure).

- Studies of science as intellectual property show that, as international economic growth is increasingly based on knowledge, so too is scientific knowledge increasingly valuable to economic and political goals (Etzkowitz & Webster 1995).

- Claims that science is exceptional or special in public policy can be analysed in terms of four essential goals, that it results in: knowledge or truth; an esoteric complexity beyond the average citizen; self-governing norms; or a unique contribution to national economic well-being. Each of these has been used in arguing for strategic and material improvement in US public policy (Bimber & Guston 1995).

- Utilitarian goals of science in western democracies foreshadow increasingly similar future science priorities, in more and more countries, as given in national science policies (Elzinga & Jamison 1995).
A significant proportion of the world's science effort is directed towards military purposes (Smit 1995).

There is tension, in less developed countries, between universal science which favours Western goals, and localised science that addresses local problems and goals (Shrum & Shenhav 1995).

There is tension, internationally, between the notionally unifying tendency of the universal goals of science and technology, and competition between companies and nation states, whose goals conflict (Ancarani 1995).

To select one of these accounts as an example, Cozzens and Woodhouse reviewed studies of the interrelationships between science, government and industry, and the politics of scientific knowledge, from which they concluded that this interplay 'is in fact the most influential power relationship running through the politics of science', yet it is underrepresented in and undervalued by the literature (Cozzens & Woodhouse 1995, p. 548). They identified US post-war involvement of industry in not just applied science, but the directions and funding of so-called pure research also. Even though industry funding of pure research increased mostly from the 1980s, thereby changing the mix of public and private research funding, there was a longer tradition in which captains of industry advised government, and 'pure academics' served on the boards of private companies. Marxist studies thus interpret this goal as the state 'providing conditions for the accumulation of capital' by the exploitation of knowledge from state-funded research; non-Marxist studies interpret the goal slightly differently, as the state supporting early, tentative and unprofitable research that business could not afford to risk (Cozzens & Woodhouse 1995, pp. 548-9). Whatever the interpretive perspective, and whether in liberal democracies or other social systems, there is a clear goal argued for science in underpinning or 'driving' the economic well-being of the country. Thus the notion of industrial sciences includes not just the research and development carried out on the premises of private and state industries, but funded, 'applied' research within the universities and a considerable proportion of 'pure' scientific research whose funding, and hence purpose, is influenced by a broader group of stakeholders than an academic community of scientists.

As a final and specific example, utilitarian purposes of science are clearly identifiable in recent science policies, as, for example, in Australian science policy on pure and applied science8.

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8 See Appendix B.1.
3.6 Critical perspectives on scientific purposes

It is clear that much of the substantial corpus of research reviewed in section 3.5, above, has more to say than merely identifying the increase and pervasiveness of utilitarian purposes of science. It is not just that science, government and industry are related, but that in this interrelatedness they share common goals. The STS literature in particular provides compelling critiques that the cognitive goals (of seeking objective knowledge) traditionally used to characterise science simply fail to account for the directions or ends taken by scientific research; this is quite aside from philosophical critiques of positivism or empiricism. It has strong implications for the interaction of the public with science. When public interest groups question or oppose science that is aligned with industry and government goals, they seek to acquire and legitimise their own knowledge base. Cozzens and Woodhouse (1995) have given examples of these complex interrelationships between goals, notably in the politics of research funding, the problems of expertise in policy making, challenges to the authority of professional knowledge and the relations between science, business and government.

Straightforward cognitive goals are not usually a problem where a knowledge dispute remains clearly within the scientific community. The purpose is agreed to be the development of scientific knowledge (Martin & Richards 1995, p. 512):

Sometimes the scientific evidence is incomplete or contradictory. In these cases, scientific debate is legitimate. Once the uncertainties are resolved, though, only a few maverick scientists can be expected to hold out against the persuasive power of the evidence …

Sometimes there is genuine cognitive controversy. Different scientists appear to have valid reasons for different reasons about nature. In most cases, this does not persist once various objective tests have been made, such as definitive experiments and repeated replications …

A limitation of [this] positivist approach lies in its dependence on scientists for determining what should be studied. (Martin & Richards 1995, p. 510)

Martin and Richards' reference to this as a positivist approach refers to its derivation from internalist, positivist characterisations of science, it being one of four models they identify for analysing decision making in science. It is not restricted, however, to the philosophical position of positivism; rather, it applies whenever the debate simply concerns cognitive goals, notably in debates within the scientific community. It does not apply well when the debate is not confined to scientists, as in public disputes and in industrial science; hence the critiques.

The goals of modern science and the diminution of cognitive goals

The first critique is that utilitarian purposes of science cause deviations from characterisations of so-called 'pure' science. That is, quite apart from any 'addition' of
utilitarian goals, the cognitive goals traditionally associated with science are diminished and fragmented:

Technification of the natural sciences - despite its undoubted achievements - is causing serious problems even in standard scientific work. Ravetz has explored at length the problems of what he calls 'industrialised' science, which is very largely technified science. The loss of skill and craft competence among the general run of research workers as a result of the overutilisation of big machines, methodological techniques and routines of organised research procedure is gradually revealing all the symptoms of work in bureaucratised organisations. There is a diminution of inventiveness, a lack of personal responsibility, over-authoritativeness, and, eventually, an absence of purpose. Such science cannot even serve practical ends adequately ... as Ravetz points out ... (Redner 1987, pp. 70-1)

Thus, for Redner and Ravetz, purposes have considerable effects, and changes in purpose manifest in changes in other dimensions that the present thesis interprets as changes in activities, structures and knowledge, for example.

Differences between the goals of modern (industrialised) science and classical (idealised) science

Secondly, to the extent that science is characterised by utilitarian purposes, its character shifts. On the one hand it becomes more clearly distinguished from traditional and popular idealisations of science, that are not characterised by utilitarian goals. On the other hand science becomes less clearly distinguished from industry and government, because increasingly it shares their goals. Thus, in contrast with the traditional characterisation of science as pursuing objective knowledge of reality, scientists increasingly work to goals arising from the interests of government and industry:

Nelkin and Pollak (1979) point out that much of what passes for 'participation' in current governance can just as well be understood as attempts by the powerful to co-opt the public. Laird found this phenomenon in the Carter administration's energy policy procedures (Laird 1993), and it has long characterised nuclear waste policy (Walker et al., 1983). (Cozzens & Woodhouse 1995, p. 545)

The work of those scientists in US energy policy and the nuclear industry is devalued, even dismissed, by their opponents in the public arena because the scientific work is characterised as directed toward the goals of the government and nuclear industry, and these bodies have vested interests in certain outcomes. Thus the goals of science are increasingly at odds with popular idealisations of science, particularly in the second half of the twentieth century.

Martin and Richards (1995) have argued that different analyses of science decision making apply in different circumstances and yield different insights. Thus disputes within the scientific community can be analysed using the positivist model, mentioned above, and for the sociology (construction) of scientific knowledge; disputes outside the scientific community can be analysed fruitfully in terms of the politics of the disputing parties, and the social structures. They advocate analyses that integrate these approaches,
thereby providing 'a more comprehensive and coherent understanding of scientific and technical disputes ... [and] enhancing opportunities for public participation in decision making' (Martin & Richards 1995, p. 525).

The goals of modern science and its place in a pluralistic democracy

Thirdly, the science-industry-government nexus has implications for the role of science in a pluralistic democracy, since the public access to science and its goals is difficult at best:

One naive notion that runs through no small portion of the early STS controversy studies is the hope that citizen participation will somehow hold the experts accountable. STS quickly learned, however, that participation without decision power is meaningless ...

The promise of technology assessment was that it would ensure a better balance of the costs and benefits of scientific and technological progress by allowing for more democratic participation in the selection of technical choices. Genuinely opening up the channels for such participation, however, would have required a substantial shift in control over decision-making away from private into public channels. This ... was a step that neither the scientific, the corporate, nor the political establishment was willing to take. (Dickson 1984, p. 259)

A major barrier to effective citizen participation in government decision making is the subtle denigration of nonprofessional knowledge in the educational system and throughout government interactions ...

A common view among scientists is that the public is neither interested nor competent in the governmental matters scientists deal with. (See Prewitt 1982) According to this argument, a deficit of knowledge disqualifies citizens from participating in science-intensive areas such as regulatory policy. (Cozzens & Woodhouse 1995, pp. 545-6)

Thus the access of citizens to scientific knowledge and expertise is systematically denied, and that this is only overcome through strenuous efforts largely without help from the scientific community. This conclusion is supported by many studies. For example, Martin and Richards' study, above, argued that understanding scientific concepts alone is necessary, but unlikely to be sufficient, for the public participation in scientific matters that concern them. Studies of the public understanding of science are no more encouraging, suggesting on the one hand that many projects carried out in the name of 'public understanding of science' tacitly serve to legitimise existing scientific practice, and on the other that scientists are less committed than the public to goals of testing and reformulating scientific knowledge (Wynne 1995). The scientific community argues that it cannot be retesting every proposition every time a citizen disputes it, for that would quash any progress at all; citizen groups argue that in public disputes involving science claims the phenomena causing concern are underplayed by the science establishment, whose goals are too often suspect because they are not value-free.

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9 The present thesis extends this critique to argue that understanding science concepts is necessary, but in combination with having understandings of other dimensions of science.
There are counter examples. Cozzens and Woodhouse point to 'dozens' of studies that show how citizens have sought to build their own body of scientific knowledge in reaction to what they perceive as threats to their lives or communities, such as matters of pollution. It is interesting that these arise from goals both different to those of professional scientists (solving different problems) and similar (claims conforming to similar standards and criteria):

[S]tudies of local controversies [show] that local knowledge is often more accurate or complete, even by conventional scientific standards, than the knowledge imported by 'experts' to a local situation …

[Contemporary social] movements seldom begin from knowledge goals. Instead, they develop them in the process of trying to solve some other problem. (Cozzens & Woodhouse 1995, p. 546)

The goals of modern science and anti-science sentiments

Finally, the science-industry-government nexus is given in shared goals, and this fuels popular anti-science rhetorics. The protest movements from the 1960s are well known examples, in which large social movements in western countries opposed war and the military industries, the atomic bomb and nuclear industries, and polluting industries and technologies. Accompanying this was widespread criticism of the involvement of science in all of these issues that were suddenly and widely unpopular. At the same time, other issues became more popular, such as non-Western medicine and philosophies, in part because they represented a rejection of (western) science. This is well documented. It can be interpreted as part of the attempts by citizen and community groups to resolve conflicts with the science-industry-government nexus:

Professional science and citizen knowledge are often complementary, in different ways in different situations. When one looks back at the science-government relationship from this viewpoint, it appears that there are a number of areas where citizens care enough about the issues to build their own knowledge bases with which to challenge professional knowledge. The battlegrounds of the politics of knowledge are not necessarily fields of science but the issues raised in government by a range of contemporary social movements.

These movements seldom begin from knowledge goals. Instead, they develop them in the process of trying to solve some other problem. In the process of neighbourhood environmental protest, for example, citizens may realise that the observations that spurred them to action - illness, visible pollutants, foul smells - are being discounted in favour of contradictory 'scientific' evidence that claims safety. The political issue then becomes knowledge itself - whose will count, that is - as protest groups fight to have their own experience counted as real, true and valuable. The women's health movement likewise revalues women's understanding of their own bodies and deprofessionalises the health care setting … The wider alternative health movement, as well as the deep ecology movement, have developed similar critiques of the limitations of professional knowledge and the political implications of science. The debates over abortion, creationism, and animal rights also illustrate that various American publics are willing to retrieve the definition of key aspects of their lives and cultures from the experts, when enough is seen to be at stake. (Cozzens & Woodhouse 1995, pp. 546-7)
This presents three matters concerning goals. First, Cozzens and Woodhouse show in this list of issues where citizens have sought to redefine concepts that are used both for their own cultural identities and by science. While this is interesting, it is not as problematic as the potential mix of outcomes that it implies: there is a likely tension between issues that are usefully ‘redefined’ by citizens, as when pollutants have been identified despite lack of access to official data, and those where the ‘usefulness’ is open to debate. Examples of the latter, of course, raise immediately the question of ‘use’ to whom, but one could suggest medical treatments with a demonstrated efficacy that have been rejected on the basis of a religious or other beliefs. There is a tension, for example, between seeking to have women claiming greater control over their health and not being denied treatments that are available and effective. Secondly, there can be a tendency to characterise conflicts between citizens and the scientific community, especially where the citizens win out, as seizing upon and rectifying a premature or misguided (or mis-directed) conclusion by scientists: that is, as a scientific aberration or pathology. The genre of studies reviewed by Cozzens and Woodhouse (and by the other essays in Jasanoff et al) is more critical: it identifies this as a structural and inherent characteristic of science when its goals identify it as part of industry and/or government. Thirdly, an argument given by scientists that they do not share the goals of industry and government, is that science is value-free and neutral, that its goal is objectivity. For example, Lipscombe and Williams (1979) have analysed arguments from scientists and others for the neutrality of science, of which the following example, although perhaps overwrought, sharply characterises the strength of views opposing science in the anti-Vietnam war movements of the 1960s:

Whether one takes an optimistic or pessimistic view of the probable consequences of the massive transformation of the natural and man-made [sic] environment and the conditions of social life that are tradeable in the end to the innocent classical delight in knowledge, the conclusion is inescapable, that the claim of moral innocence must now be dismissed as a mere vestigial survival of an earlier and safer era. It is one thing for a pure geometer to demand to be left alone ... It is quite another thing to hear the same plea of moral blamelessness and ‘neutrality’, in the sense now of moral innocuousness, made by contemporary scientists working directly, say, for the military establishment. When the immediate consequences of scientific activity are so plain and so obvious, a plea of ‘scientific neutrality’ can only be properly characterised as an expression of deliberate myopia or, to put it more bluntly, moral irresponsibility.

Allow me to offer an example of this kind of irresponsibility. In The New York Times for December 27, 1967 (p. 8), there appeared an interview with Dr Louis Frederick Fieser who was in charge of a team of Harvard University scientists developing napalm during World War II. He is reported as having said that he felt free of ‘any guilt’. He is also quoted as saying ‘You don’t know what’s coming. That wasn’t my business, That is for other people, (my italics) I was working on a technical problem that was considered pressing.’ He went on to say: ‘I distinguish between developing a munition of some kind and using it. You can’t blame the outfit that put out the rifle that killed the President. I’d do it again, if called upon, in defence of the country.’ When asked about the use of napalm in Vietnam, Dr Fieser said, ‘I don’t know enough about the situation in Vietnam. It’s not my business to deal with political or moral questions. That is a
very involved thing. Just because I played a role in the technological
development of napalm doesn’t mean I’m any more qualified to comment on the
moral aspects of it.’

The moral callousness of these remarks is matched by their confusion of
thought … (Lipscombe & Williams 1979, pp. 51-2; emphases in original)

Lipscombe and Williams object to the notion expressed that one needs ‘moral
qualifications’ in order to assess the consequences of one’s action, as an ethical matter.
But in the present argument, we might also object that this scientist confuses or mis-
identifies the goals of his activity: what he represents, and no doubt believes, is that he
was working towards a disinterested and objective solution of a technical problem.
Lipscombe and Williams’ implicit objection is that the scientist failed to identify that his
work was directed towards a larger goal of producing a technical product with military
uses. In their first paragraph, Lipscombe and Williams reject the isolation of purely
knowledge goals from the goals that drive the development of the knowledge in the first
place. This is the same argument that has been put forward by community groups who
oppose polluting industries, for example, and the use of live animals in experiments: they
do not accept that the goal is the disinterested pursuit of knowledge. The present thesis
interprets these different goals as arising from differing belief systems, in particular
different beliefs about whether science is value-free or value-laden.

In closing, we have noted tensions between the largely institutionalised authority of
science and the interests and needs of citizens. Such tensions are central to notions of a
scientifically literate citizenry and therefore, the present thesis argues, to the school
science education of future citizens.
Table B.3.1
Examples of characterisation of key metascientific viewpoints by purpose

<table>
<thead>
<tr>
<th>Author</th>
<th>Viewpoint</th>
<th>Examples of reference to purpose</th>
<th>Identified in the work of</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suppe 1973, 1979</td>
<td>Received View</td>
<td>To generate empirically verifiable knowledge; to construct an account that can be rationally reconstructed</td>
<td>Carnap</td>
</tr>
<tr>
<td></td>
<td>sceptical descriptive</td>
<td>(a) To generate an account that reflects identifiable aims (b) To generate an account that meets one or more of several criteria (such as mathematical and semantic criteria)</td>
<td>(a) Achinstein (b) Rapoport</td>
</tr>
<tr>
<td></td>
<td>Weltanschauungen (world view)</td>
<td>To construct knowledge that is consistent with a Weltanschauungen</td>
<td>Bohm, Feyerabend, Hanson, Kuhn, Popper, Toulmin</td>
</tr>
<tr>
<td></td>
<td>semantic or model-theory</td>
<td>To describe, predict and explain phenomena within an intended scope</td>
<td>Beth, Suppe, Suppes, van Fraassen</td>
</tr>
<tr>
<td></td>
<td>historical realism</td>
<td>To develop knowledge of the world that is philosophically justified</td>
<td>Lakatos, Shapere, Toulmin</td>
</tr>
<tr>
<td>Bhaskar 1983</td>
<td>empiricism</td>
<td>To generate knowledge of the world by the inductive analysis of experiences.</td>
<td>Francis Bacon, Berkeley, Hobbes, Hume, Locke, Mach (positivism), Mill, Russell, Vienna Circle (logical empiricism)</td>
</tr>
<tr>
<td></td>
<td>idealism</td>
<td>To construct knowledge by mental activity.</td>
<td>Berkeley, Fichte, Hegel, Hume, Kant, Plato, Schelling</td>
</tr>
<tr>
<td></td>
<td>realism</td>
<td>To generate knowledge of an external reality.</td>
<td>Aristotle, Bachelard, Bhaskar, Duhem, Feyerabend, Hanson, Harré, Hesse, Hume, Kant, Koyré, Kuhn, Plato, Popper, Putnam, Quine</td>
</tr>
<tr>
<td>Nussbaum 1989</td>
<td>rationalism</td>
<td>To generate or discover proven, true or confirmed knowledge</td>
<td>Descartes, Kant, Plato</td>
</tr>
<tr>
<td></td>
<td>empiricism/positivism</td>
<td>To generate or discover proven, true or confirmed knowledge</td>
<td>Bacon, Comte, Hempel, Hume, Locke</td>
</tr>
<tr>
<td></td>
<td>constructivism</td>
<td>To generate the best available knowledge according to (a) internal criteria (rational, logical, empirical) (b) external criteria (social, historical, psychological)</td>
<td>(a) Popper, Lakatos, partly Kuhn (b) Kuhn, Toulmin, partly Lakatos</td>
</tr>
<tr>
<td>Boyd, Gaspar and Trout 1991</td>
<td>empiricism</td>
<td>To generate knowledge of the world that is consistent with experimental (a) verification (Carnap, Hempel) or (b) falsification (Popper)</td>
<td>Carnap, Hempel, Hume, Popper</td>
</tr>
<tr>
<td>Post-positivist consensus comprising (a) post-positivist empiricism, (b) neo-Kantian constructivism, and (c) scientific realism</td>
<td>To produce explanations of experimental data that correspond with the facts or with reality.</td>
<td>(a) Partly Popper (b) Hanson, Kuhn (c) Boyd, Goodman, Kripke, Putnam, Quine</td>
<td></td>
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<tr>
<td>Pickering 1992</td>
<td><strong>scientific knowledge as objective (logical empiricism)</strong></td>
<td>To generate true or verifiable knowledge of the world</td>
<td><strong>Kuhn, Feyerabend</strong></td>
</tr>
<tr>
<td></td>
<td><strong>scientific knowledge as relative to culture</strong></td>
<td>To extend the culture’s knowledge of the world</td>
<td><strong>Barnes, Bloor, Callon, Cartwright, Collins, Garfinkel, Gilbert, Knorr Cetina, Latour, Law, Lynch, Mulkay, Shapin, Woolgar</strong></td>
</tr>
<tr>
<td></td>
<td><strong>scientific knowledge as relative to interests (sociology of scientific knowledge - SSK)</strong></td>
<td>To construct knowledge of the world for use, not simply for contemplation.</td>
<td><strong>Hesse, Holton, Popper</strong></td>
</tr>
<tr>
<td>Callon 1995</td>
<td><strong>science as rational knowledge</strong></td>
<td>To generate statements and networks of statements (codified knowledge) about the natural world.</td>
<td><strong>Althusser, Ben-Cole, David, Freudenthal, Hull, Merton, Popper</strong></td>
</tr>
<tr>
<td></td>
<td><strong>science as competitive enterprise</strong></td>
<td>To generate statements about the natural world, to test these statements, and to scrutinise the statements of others.</td>
<td><strong>Bachelard, Barnes, Collins, Fleck, Knorr, Kuhn, Mulkay, Pinch, Ravetz, Rudwick, Schaffer, Wise, Wittgenstein</strong></td>
</tr>
<tr>
<td></td>
<td><strong>science as sociocultural practice</strong></td>
<td>To generate knowledge meeting both cognitive and sociocultural goals.</td>
<td><strong>Amaan, Callon, Foucault, Knorr Cetina, Latour, Pickering, Wise, Woolgar</strong></td>
</tr>
<tr>
<td></td>
<td><strong>science as extended translation</strong></td>
<td>To link technical devices, statements, and human beings in stabilised relations in order to produce statements about the world.</td>
<td></td>
</tr>
</tbody>
</table>
Appendix B.4

Argument from the metascientific literature emphasising the dimension structure

Debates in the metascientific literature address many aspects of structure in science, which again supports a broad interpretation of structure as a dimension of characterisation. Appendix B.4 addresses this scope as follows:

B. 4.1 Current metascientific views with respect to structure;
B. 4.2 The unity of science;
B. 4.3 The role of structure in characterising a western European scientific tradition;
B. 4.4 Structures of knowledge (cognitive structures)
   a) laws
   b) theories
   c) disciplines
   d) other cognitive structures
B. 4.5 Organisational structures
B. 4.6 Language structures

4.1 Current metascientific views with respect to structure

Metascientific argument in the literature presents various notions of structure. Table B.4.1 summarises several analyses of metascientific viewpoints, to enable some comparisons based on notions of structure. Each view addresses at least one aspect of structure explicitly, and usually more than one.

In contemporary HPS, the current consensus is that there are three main positions: post-positivist empiricism, idealism or neo-Kantianism, and scientific realism. In empiricism, the central notion of structure is structures of knowledge - inductive structures of experiences and deductive structures from hypotheses - on which organisational structures are based. Thus disciplines as organisations arise from, and closely reflect, disciplines as intellectual and logical structures. In idealism, structure also centres on knowledge, but knowledge as structured by the intellect; organisational structure varies more between accounts, but tend to focus on the human and social characteristics of scientific structure. Scientific realism characterises science knowledge by several notions of structure. First, the possibilities of our knowledge of the cosmos
are constrained, or structured, by an external reality; second, this knowledge is socially produced, or structured. Thus this view combines several notions of structure at its focus: natural (ontological), knowledge (epistemological) and social and psychological structures.

In contemporary STS, Callon (1995) has described four main approaches. (a) Where science is characterised as *rational knowledge*, it concerns the structures of scientific statements. The meanings of these statements are assumed to arise simply and transparently ‘in the system of the statements’ (Callon 1995, p. 42). Social structures arise from these cognitive structures, and serve them by providing the unfettered space for free and frank discussion. (b) Where science is characterised as a *competitive enterprise*, the internal structure provides a system of rewards and sanctions. There is no agreed explanation of the roles of laboratories and research teams. The external structure makes a clear distinction between the structures of science and those of non-science; boundaries are clear and firm, but allow some nourishment to and from society. This model of structure also applies to science as rational knowledge. (c) *Science as sociocultural practice* emphasises the social characteristics as much as the disciplinary ones, but it makes weaker references to structure than the first two models. Because it takes science to be a human activity alongside all other human activities, an emphasis on sociocultural practice concerns tacit knowledge, as proposed by Polyani. Tacit knowledge is implicit and uncodified (unstructured) compared with formal knowledge, although it includes structures such as rules and ‘language games’ (Callon 1995, p. 42). However, the perspective of science as sociocultural practice is less concerned with organisational and institutional structure. It does address rules, by which social organisation is possible, and which help to understand power structures such as master-disciple relationships. Boundaries between science and its environment are ‘constructed by actors themselves in various hybrid settings’ and are therefore contextual rather than absolute structures (Callon 1995, p. 49). The meanings of scientific statements are not given just in their structure, as for science as rational knowledge, but in their context too. (d) *Science as extended translation* is concerned with the production of statements, as in model (a), but is concerned with the process of their production and ‘nonpropositional elements in this process’ as in model (c) (Callon 1995, p. 50). Thus it characterises the structure of translation chains of statements, where the coherence between actants (technical devices, statements and human beings) provides the meaning of statements about the world.
4.2 The unity of science

It is more common, both in the literature and in general public contexts, to speak of science rather than sciences. Some theorists seek to discern a single, underlying, unitary structure of science. There are two broad notions of the unity of science, both of which are contested: that essentially the sciences are similar in their methods, or their results (Sober 1995).

Methodological unity holds that the reasoning activities of the various sciences are similar across the sciences. Discussions of the scientific method in many general science texts seem to make this assumption, but the notion of methodological unity is strongly criticised and rejected in much of the post-positivist literature. In any event there is no clear notion of what a uniform method of reasoning refers to. There seem to be some general notions of unity, but the nature of this unity is unclear. For example, Sober (1995) has argued that while it is 'doubtless' that all sciences use the same technique of reasoning (the structure if A, then B, or modus ponens), it is not clear that all sciences use other techniques, either logical or practical, uniformly (Sober 1995, pp. 501-2). In a similar way, Duschl (1994, p. 449) has noted some striking similarities between Kuhn's notions of normal and revolutionary science, based on physics, and Schwab's notions of stable and fluid science, based on biology. Like Sober, however, Duschl does not see any structural unity beyond these general notions. The trend in much of post-positivist metascience seems to be an increasing interest in differences between sciences. For example, in their review of HPS, Boyd, Gasper and Trout include chapters on emerging differences in the philosophies of different sciences; in their review of STS, Jasanoff et al include chapters on different constructions of science, including different characterisations (Callon) and constructions of boundaries between science and non-science (Gieryn).

Unity of scientific results is the view that the theories in one science can be subsumed under, or reduced to, the confirmed theories in another science. Most commonly this is taken to mean that sciences such as sociology and biology can be reduced to theories in physics and mathematics. Reduction of theories is one of the tenets of the positivist RV, and is one of the tenets on which the RV has been largely rejected in metascience (Suppe 1979; Horgan 1995).

The idea of the unity of science now probably relies on the lingering influence of positivism and the popular use of the term science. The present thesis refers mostly to

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1 See the discussion of the scientific method in Appendix B.5.
science to be consistent with the common use of the term science as the basis for the curriculum subject, Science. In doing so, however, it recognises that the post-positivist literature gives grounds for caution, at least, in ignoring the variation that the singular science can imply.
4.3 The role of structure in characterising a western European scientific tradition

Various notions of structure have changed over time and characterise a historical tradition. The present section will confine its scope to structures of knowledge. This is useful because, as noted above, there are links between the structure of knowledge, a common and traditional category of characterisation, and the organisational structures of science: study of one informs the other. Whether one is concerned initially with intellectual or organisational structures, the history of science shows that (a) there is a relationship between the two, evident in the university faculties and departments based on scientific disciplines - biology (even zoology, botany and genetics), physics, chemistry (again, even as organic, inorganic and physical) and so on - and (b) these structures were not always so, and in many instances are historically recent.

Machlup (1982) has demonstrated some historical links between the knowledge-structure and institutional-structure of science using examples of attempts to map the sciences (in Part One) and to construct departments of erudition (Part Two). The historical summary of some of these structures, given in the present section and in Table B.4.2, also relates to the discussions of knowledge concepts (Chapter 11 and Appendix B.6), beliefs about the nature of reality and the appropriate way to relate to reality (chapter 7 and Appendix B.2), and context (Chapter 6 and Appendix B.1). This illustrates both the interconnectedness of the dimensions and the value of structure, as a distinct dimension of characterisation, in providing insights useful for understanding the nature of science as characterised in the literature. The present section is based upon Machlup's characterisation, using some of his examples and noting his acknowledged limitations: he addresses intellectual, and not other kinds of knowledge, and he makes no attempt to give an exhaustive account of knowledge structures in history. Likewise, the present section and Table B.4.2 make no claim to being exhaustive, but instead attempt to indicate a historical tradition using sufficient scope and depth to show how various aspects of structures have changed while others have been more enduring. While based on Machlup's account, it is supplemented with details from other accounts. There is some variation between accounts; an example is discussions of Aristotle, where the details given by Machlup, Irwin and Oldroyd vary, and in some respects the accounts have little in common, but this detail is beyond the scope of the present thesis.

Machlup is clear 'that classifications are made for different purposes and by different types of people' (1982, p. 19), a conclusion that applies equally to the present
thesis. Accordingly, he distinguishes four basic types of approach to knowledge classification, remembering that individual attempts may embody more than one of these:

[First are] the philosophers, whose only purpose is to facilitate orderly thinking, systematic analysis of the universe; their chief concern is an overview of things (chiefly abstract) and an understanding of their interrelationships. There are the encyclopaedists, who want to present their work in a systematic but not alphabetic order; they are concerned with orderly presentation of their material, with outlining and organising the universe in a methodological way so that the reader might comprehend where all the things should be placed, and where he [sic] should look for them if he wants to gain deeper insights. There are the bibliographers, whose task is to help readers and researchers become aware of all, or of the most important, publications in their special fields; complete listings secure the cumulative character of knowledge formation, promote the generation of new or amended knowledge, and can avoid loss of knowledge previously created, duplication of research previously completed, and repetition of error previously corrected. Finally, there are the librarians, concerned with orderly listing of published titles in all fields of knowledge, orderly stacking of volumes, and orderly cataloguing, to help the user of books and journals find what he wants to read or consult. (Machlup 1982, p. 19)

While we will not concern ourselves with the detail of this argument, Table B.4.2 shows a variety of approaches that are also noted in the following historical sketch. The details of category labels (but not always content) are given in Table B.4.2 because that presentation conveys, better than paragraphs of text, the notion of structure. The notations are not intended to be equivalent between examples, or to represent the original notation of the authors in question; their purpose is to help make clear the structures.
The arrangement of knowledge is structured, not given

The most significant point to note from a historical summary is not the value of any particular structure, but that the structure and inter-relatedness of knowledge, familiar in contemporary science, is a human construction; it is neither a ‘given’ nor self-evident. Historical examples show that knowledge has been analysed and ordered in a variety of ways: some show direct influences on current structures while others were alternatives that have been considered.

For example, Aristotle (384-322 BC) made numerous distinctions, many of which remain familiar today, although ‘despite all this classificatory work, Aristotle was not among those who presented a comprehensive system of all the sciences known at his time’ (Machlup 1982, p. 23). Porphyry (AD. 232-302) is usually credited with the metaphor of a tree of knowledge, whose branching symbolises the dichotomous divisions by which we commonly categorise or structure knowledge. Some later thinkers re-named Porphyry’s tree as Porphyry’s ladder, to symbolise better starting at the ‘top’ with undifferentiated knowledge, and the ability to move ‘up’ and ‘down’ through the analysis.

Perhaps the best known structuring of knowledge in classical and mediaeval times was the division of the seven liberal arts into the Trivium and Quadrivium: studies were arranged respectively into the artes (grammar, rhetoric, dialectic) and disciplinae (arithmetic, geometry, music, astronomy). These arose from traditional lists of disciplines, notably those compiled from Aurelius Augustinus (Saint Augustine, 354-430); early proponents included Capella (before AD. 439) and Cassiodorus (before 550).

One of the most influential encyclopaedic efforts in the late Middle Ages was Robert Grosseteste (c. 1175-1253), whose Compendium provided a classification of the scientific knowledge available at the time. Grosseteste strongly influenced later thinkers: Albertus Magnus (1193/1206-1280), who exhaustively compiled Aristotle’s work and sought to increase understanding of knowledge (philosophy); Thomas Aquinas (Saint Thomas, 1227-1274), divided science according to roles of the intellect; and Roger Bacon (1214-1292/94), who sought to show that science has a unitary and interconnected structure. Particular points to note are that Aquinas excluded history from science, unlike many thinkers from the 16th to 19th centuries, and that Bacon combined mathematical and experimental methods. Ramon Lull (or Raymond Lulle, 1234-1315) also used the metaphor of the branching tree, but unlike Porphyry (and later, Francis Bacon), proposed as many as sixteen rather than a single tree. Machlup also describes an equivalent Arabic tradition, with origins traced back to Aristotle, that sometimes parallels, and sometimes
predates, similar work by the western Europeans. For example, Muhammad al-Farabi (d. 950) catalogued the known sciences, and Ibn Sīnā (Abu Ali, 980-1037) later extended these. Machlup notes particularly the inclusion of dream interpretation and charms among physics in the latter (1982, p. 30). Ibn Khaldūn (1332-1406) sought to distinguish science (knowing) from crafts (doing), although he notes that some fields, like medicine, combine the two. Note also that he distinguishes the 'intellectual sciences', based on reason, from the traditional or religious sciences, based on religious authority. He includes the sciences of sorcery (magic) and talismans in the former, and refutes and condemns philosophy and astrology.

Before continuing, we should note that these classical and mediaeval synopses of knowledge establish a tradition of interpreting the term *science* more broadly than just the natural sciences or the empirical sciences. The broader tradition is more consistent with the non-Anglo-American use of the term today, as given in summary statements 21 and 22 (both Machlup). This distinction can be seen starting in the Scientific Revolution, the example here being Francis Bacon's work, from which time structures more closely resemble contemporary arrangements.

The metaphor of a branching tree for the structure of knowledge, widely known in recent times, stems mainly from its extensive characterisation by Francis Bacon (1561-1626):

Bacon's classification of learning - his *partitiones scientarium* - became the model for almost all later taxonomic and encyclopaedic efforts regarding intellectual knowledge ... Bacon's taxonomic zeal led him to enumerate, explicate, and illustrate the 'divisions of the sciences' at great length. (Machlup 1982, p. 35)

The structure of the tree was used effectively to convey the notion of relationships between branches or fields of knowledge, especially as they arise from the intellectual activities that comprise Bacon's three main divisions. In particular, Bacon noted relationships between physics, mathematics and logic, and the expected structural changes as physics continued to develop. From other taxonomic efforts of the time, Machlup also mentions that of René Descartes (1596-1650) as one of the many that used the tree metaphor, and of Thomas Hobbes (1588-1679) as one that did not.

Between the seventeenth and twentieth centuries there was considerable work done on the structure of knowledge, including the development of encyclopaedias, but we will confine our attention to a few accounts that influenced thinking about scientific knowledge. Immanuel Kant (1724-1804) did not provide a classification of science, but his writings, which dealt with epistemology and methodology, provided a structural basis for later thinkers that was very influential:
Kant’s analyses of the distinctions between analytic and synthetic, phenomena and noumena, intuition and perception, theoretical and practical, immanent and transcendent, empirical and transcendental, and many other contraries and contradictories laid the groundwork for the reflections of generations of classifiers and taxonomists of the branches of learning. (Machlup 1982, p. 60)

For example, Georg Hegel (1770-1831) was influenced by Kant’s critique of the limits of reason and subjective elements in knowledge. He proposed a categorisation of knowledge by consecutively dividing parts into three. Following the work of Fichte, this follows a formula of thesis-antithesis-synthesis, through a dialectic process of affirming and negating. Although Machlup notes an ambivalence in the influence of Hegel’s approach, Westphal (1993) notes that ‘Hegel was the first epistemologist to realise that a socially and historically based epistemology is consistent with realism’ (Westphal 1993, p. 168). Hegel’s account of knowledge thus contains externalist elements and marks the starting point of continental epistemology (Alcoff 1993). André Ampere (1775-1836), better known for his work in electricity and magnetism, proposed a scheme in 1834 that, although complex, has a structure that bears a closer resemblance than its predecessors to contemporary arrangements, particularly in its clearer distinction between biology and physics, and between physics and metaphysics. Auguste Comte (1798-1857) envisaged knowledge of the world as developing through three stages; from the theological, through the metaphysical, to the final positive stage. Since he thought that the sciences in his day were at or approaching the third, positive, stage, he considered earlier attempts to categorise scientific knowledge as failed, and the time ripe for his own categorisation. Comte’s categorisation shows clear links with current conceptions. This is due in part to the categories themselves and the terminology used being so familiar. The hierarchical ordering is also familiar, beginning with mathematics, which he saw as starting with the simplest and most general and proceeding to that which is the most complex and concerned with the specific. This ordering continued into the twentieth century, influenced by the positivist school of thought. Karl Pearson (1857-1936) proposed a structure in 1892 that was very influential at the turn of the century and beyond; he rejected Comte’s reductionist approach, but still provided a scheme which separated mathematics (abstract or conceptual sciences) from the ‘perceptual’ domain: his three fundamental divisions were abstract, physical and biological sciences. His scheme appealed to the prevailing positivist view by allowing only a descriptive, and not explanatory, role for scientific knowledge, and rejecting any notion of metaphysics as scientific knowledge.

Of the accounts that arose in the twentieth century, we will mention two accounts that sought to show the interrelated structure of scientific knowledge. One is the positivist
RV, identified in the work of Otto Neurath (1882-1945) and Rudolf Carnap (1891-1970), that argued an interrelated structure through the notion of unified science. The other is the fifteenth edition of the *Encyclopaedia Britannica* (1974), under the chairship of Mortimer Adler, that argued an interrelated structure through a fresh concept of a *circle of learning*, whose 'centre' is the knowledge of knowledge. The circle structure is used to represent a non-hierarchical and non-linear structure of knowledge. Finally, Table B.4.2 includes the categories used in the *Dissertation Abstracts International* for science and engineering. This structure is used not to demonstrate interrelatedness, but comprehensiveness, because it seeks to include all possible theses published in science and engineering.
4.4 Structures of knowledge

There is a sense of structure in science that relates, either directly or indirectly, to the ways in which we order or arrange scientific knowledge. Science is commonly identified, both in scientific and public contexts, by terms such as laws, theories and disciplines: the present section will argue that each of these relates to structures of knowledge but imprecisely so. To some minds it may seem odd that scientific laws, theories and disciplines should be characterised as structures, albeit partly so: that surely they are simply statements of knowledge. The present thesis argues in the companion chapter on knowledge and Appendix B.6 that science knowledge is not as straightforward as simplistic characterisations imply. The present chapter, especially in this section, draws attention to the ordered, structured or composed character of science knowledge, and to differences in structures and their meanings. Science knowledge is not expressed, for example, in free verse, musical notation, or narrative: it is expressed in characteristic forms that we identify as laws, theories, mathematical structures like axioms, and so forth. Yet these are sometimes used imprecisely: while laws and theories are frequently mentioned together, often they are not distinguished from each other. Where they are distinguished the difference in their meanings is significant: they refer to different structures. Put rather baldly, the ordering of sense data - the empirical information - so that we might make sense (order) out of their complexity gives the structures called scientific laws. Alternatively the way we construct and arrange propositions and other statements so that they form descriptions and/or explanations gives structures called theories. Of course, notions such as laws and theories are a good deal more complex than this, but the point here is that laws and theories are structures used in science, and by which the literature partly characterises science. The notion of a scientific discipline is also unclear, because disciplines as knowledge structures - physics, geology and so on - are also the basis for organisational structures, such as departments or faculties of physics and geology. This is especially interesting when new, cross-disciplinary fields emerge, such as geophysics, biophysics and biochemistry. The remainder of this section outlines these and some other variants of structures relating to knowledge.

a) Scientific laws as structures

As with other aspects of metascience, there are various notions of laws, and indeed interpretations of the term law:
'Law' is ... used ambiguously to refer to both statements and what statements designate (e.g. ‘Ohm’s Law’ refers to a proposition and what the proposition describes, viz. a relation between certain variables).

Many different kinds of statements, or phenomena, are called 'laws'. They include constitutive, dispositional, developmental, quasi-teleological, abstract and idealised properties, processes and relations, ranging from observed patterns through experimentally established invariances to the fundamental theoretical principles (or quasi-analytic axioms) of whole branches of sciences; law-statements may express numerical constants or qualitative attributes, developmental sequences, identities or functional relations, statistical correlations or universal features of types of thing. (Bhaskar 1983e, pp. 229-230)

Within these uses we can discern two senses of laws as essentially structures, that they are meaningful because of structure. One is the sense, based in the long standing tradition, which is still influential, that laws are statements of natural regularity or propensity, and are therefore statements of Nature (ontology). The other, which in some views overlaps with the first, is that scientific laws are statements of knowledge (epistemology), and thus represent cognitive structures.

A scientific law is a rule or generalisation which describes specified natural phenomena within the limits of experimental observation. An apparent exception to a law tests the validity of the law under the specified conditions. A true scientific law admits of no exception. A law is of no scientific value unless it can be related to other laws comprehending relevant phenomena. (Wordsworth Dictionary of Science and Technology 1995, p. 510)

It is widely held by both scientists and philosophers that our universe is governed by scientific laws and that it is one of the primary aims of science to discover these laws. Particular scientific subjects are often organised around laws stated in the vocabulary of that subject. For example, Schrödinger's equation is central to physics, the Hardy-Weinberg law to genetics, and equilibrium laws to economics. It is also widely held that the concept of a scientific law is intimately related to other important concepts including causation, natural kind, explanation, confirmation, reduction, necessity and probability. It is not surprising then that the task of elucidating the concept of a scientific law figures prominently within contemporary metaphysics and philosophy of science. (Loewer 1995, p. 266)

First, there is a sense that laws are meaningful because of their structure; this applies whether or not one agrees with Loewer. Thus a law that can be expressed mathematically derives its meaning from that particular structure and not some other arrangement. For example, Newton’s Second Law of Motion:

The rate of change of linear momentum is proportional to the force applied, and takes place in the straight line in which that force acts. This definition can be regarded as formulating a suitable way by which forces may be measured, that is, by the acceleration they produce,

\[ F = \frac{d}{dt} (mv) \]

i.e. \[ F = ma + v \frac{dm}{dt} \]
In the majority of non-relativistic cases, $\frac{dm}{dt} = 0$ (i.e. the mass remains constant), and then

$$F = ma$$

(Pitt 1977, p. 258)

The meaning is dependent on the structure. Verbally, *is proportional to* gives a different meaning and predictive outcome to *is inversely proportion to*; algebraically, $F = ma$ gives a different meaning to $F = m + a$. Bronowski (1978) makes this point when he rejects Dionysius's belief in God as an explanation for gravity, on the basis that a belief in God does not lead to the precise mathematical structure that accounts for attraction over a distance:

Dionysius had an excellent idea - bodies attract one another - and he had a good reason to think so. But it was not a reason which was going to tell him whether the attraction fell off at the inverse distance or the inverse square. It was not a reason with which you could do any kind of manipulation. It was not a coherent reason, because it lent itself to a different kind of speculation. (Bronowski 1978, p. 9)

The second sense of structure in laws arises in views that reject Loewer's (op. cit.) claims that *our universe is governed by laws*, and that scientists *discover* them. The view that laws are ontological statements of patterns and regularities in Nature (as in empiricist accounts), and therefore that laws are discovered, is but one of several notions of laws in the literature. A second view is that laws are statements of the mental constructions by which we make sense of seemingly disparate sense data (as in constructivist accounts), and thus they are *constructed*, not discovered. This argument, found widely in post-positivist accounts, points to historical examples where laws have been revised. The common example is Newton's laws of motion, that once were believed to hold always and everywhere, but now, since Einstein's relativistic interpretation, are believed to hold as good approximations where the velocity is small compared with that of light. The lesson drawn from this example is that laws in science are revisable or tentative in principle, even though in scientific practice they may be used without question: if they are revisable in principle, they cannot be unchanging expressions of ontology, and must be (best available) constructions by scientists. A third view (as in scientific realism) is that laws are statements of the natural mechanisms that can, but do not always, manifest themselves as regular patterns of phenomena: they are real but our knowledge of them is limited by what we can construct. In this view, knowledge of the regularity is

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2 The verbal expression of this law is given as a regularity, although its mathematical expression is taken sometimes as a definition. In any case, the meaning depends on the structure.

3 In Kuhn's well-known characterisation of science, laws and theories are accepted and refined in *normal* science - within a paradigm - and seriously challenged only in *revolutionary* science, when there is a paradigm shift.
constructed, and we deduce this structure from empirical tests of possible explanations of regularities (Bhaskar 1983e, p. 231). Each of these views provides its own insights, but they are dealt with in section 3 of Chapter 9, because scientific laws are one of the clearer examples of how science is characterised in multiple dimensions.

In brief, there are widely held post-positivist beliefs that laws are not immutable verities but are changed and even rejected as we develop better explanations. This is supported by a notion structure: in this sense, this aim has changed, from discovering to constructing, even though both can be interpreted in a broader sense of identifying such regularities, whether by discovering, constructing or some other activity. In this way, we are able to account for how science is able to describe and/or explain economically and accurately a large amount of empirical data by means of a small number of general statements, while at the same time being revisable, and therefore tentative, in principle. The empirical data is structured as observation statements; general statements are structured as law-like statements or mathematical axioms.

b) Scientific theories as structures

Theories are in some senses related to laws, and often weakly distinguished from them in general characterisations of science:

Theory:
A general, systematic account of a subject matter. Theories frequently posit the existence of unobservable (or theoretical) entities and often have the status of hypotheses, since by their nature they are harder to confirm than less general claims.

Hypothesis:
The status of a scientific claim after it has been advanced but before there is sufficient evidence to accept (or reject) it. (Boyd, Gasper & Trout 1991, pp. 777, 781)

As with other characteristics of science, there are varying accounts of what a scientific theory is. Probably the definitive characterisation of scientific theory in the Received View (RV) is Suppe (The Structure of Scientific Theories 1979). Briefly, Suppe traces in considerable detail the background, initial formulation in the 1920s, and development of the RV. The final (1960s) version of the RV characterisation of a scientific theory is complex and highly structured (see Suppe 1979, pp. 50-53) and is only paraphrased here, as follows. Scientific theories have a canonical structure, being axioms formulated in mathematical logic. This axiomatic language comprises three main elements: an observation language, whose descriptive terms only come from an observation vocabulary, and which applies only to empirical phenomena; a theoretical language, whose descriptive terms only come from a theoretical (non-observation) vocabulary; and
Appendix B.4: Structure

mixed sentences comprising both observational and theoretical terms. Observation and theoretical terms are related by the partial interpretation of theoretical terms using the theoretical language and correspondence rules using mixed sentences. The RV characterises theories by these structures; analysis of theories according to these structures is called the rational reconstruction of theories.

Post-positivist approaches in metascience have provided various criticisms of, and alternatives to, the RV characterisation of theories. Suppe (1979, pp. 62-118) discusses a number of criticisms of the RV account of theories, which we will only note here: not all scientific theories can be ‘fruitfully axiomatised’; the distinction between observational and theoretical terms cannot be sustained; the notion of partial interpretation of theoretical terms is unclear and relies on the observational-theoretical distinction; some views (as proposed by Campbell, Nagel and Hesse) require that models be constructed to make theories meaningful and, although they fail to show that the RV is inadequate, they do show much about the meaningful interpretation of theories; the RV account of correspondence rules is unsatisfactory; and it is not clear that theories can be formalised or axiomatised as required by the RV.

Sceptical descriptive views of scientific theories

There have been a number of alternative views of theory proposed in response to the criticisms of the RV version (Suppe 1979, pp. 119-232). Since we are concerned here only with structure, we will mention two groups of the alternative accounts. First are the so-called sceptical descriptive accounts, which seek not to describe what scientific theories should be like (as in the RV) but to describe them as actually used and then seek common structural features:

Central to many of the proposed alternatives to the Received View is the idea that an adequate analysis of theories will not be rational reconstruction. Rather than presenting an analysis of how theories ideally should be formulated (an ideal that theories in practice fail to meet), it is held that an adequate analysis of theories should characterise theories as they actually are employed in science. Thus the analysis of theories should be descriptive of theories actually employed in actual scientific use. Upon looking at the theories actually employed in science, some authors have been so impressed by the diversity of theories encountered and the functions they perform that they despair of ever providing a comprehensive analysis of theories which display deep properties common to all theories. (Suppe 1979, p. 120)

The example Suppe gives is Achinstein (1968), who despairs of finding any deep, common structure to scientific theories beyond the four ways he identifies that scientific theories are presented: (i) by the main assumptions of the theory (which the present thesis interprets as elements of the belief system); (ii) by the underlying motivation for the
theory (which the present thesis interprets as purpose); (iii) by the development of the theory (which the present thesis interprets as mainly activity and structure); or (iv) by confirming instances of the theory (which the present thesis interprets as mainly activity and belief system). Suppe points out that Achinstein’s analysis does not preclude a detailed, general analysis of theories, but his scepticism is supported by other attempts to describe common details of theoretical structures, such as that by Rappoport (1958):

That the entities commonly called scientific theories evidence such diversity does lend credence to the suggestion that there will not be any particularly deep or revealing characteristics common to all scientific theories other than what Achinstein incorporates into his analysis ...

I conclude ... that an examination of the diversity of theories and their intended functions does lend some support to the contention that not much is possible in the way of a general structural analysis of all theories. However, theories each fall into one of a small number of fairly homogeneous classes of theories for which there is reason to suppose deep structural properties are common to all theories in a given class; and much in the way of increased understanding of the theories could be gained by investigating the structural properties common to theories of a given class. (Suppe 1979, pp. 124)

Thus according to sceptical descriptive analyses there are no grounds to support common, deep structures in scientific theories as they are practised.

**Characterisations of theories as world views**

The second group of views is the Weltanschauungen analyses, in which science is characterised by a particular perspective or view-point. These approaches do not emphasise structure as did the sceptical descriptive approaches, but structure is part of the characterisation and varies between accounts. Thus, for Toulmin, theories comprise laws and hypotheses (which the present thesis interprets as structures) and ‘ideals of natural order’ (Suppe 1979, p. 130), which the present thesis interprets as elements of the belief system. Collectively these entail structure in that they must be composed in some way to make a meaningful whole. For Kuhn, science as a whole is structured from episodes of normal and revolutionary, or extraordinary, science. He initially characterised normal science as being done within a *paradigm*, which he defined as the ‘accepted examples of actual scientific practice - examples which include law, theory, application, and instrumentation together - [which] provide models from which spring particular coherent traditions of scientific research’ (Kuhn 1962, p. 10, in Suppe 1979, p. 136). The present thesis interprets the initial use of *paradigm* as characterising science by a combination of structure, knowledge, belief system, context and activity. Kuhn later came to characterise normal science as done within the structure of a *disciplinary matrix* (Suppe 1979, pp. 139-43), where the disciplinary matrix and the range of *exemplars* together are clarifications of his initial use of the term *paradigm*. (We shall address disciplines as
organisational structures presently.) This clarification of paradigm was in response both to criticism of its initial imprecise meaning, and its widespread and even more imprecise use by others. Significantly, though, most uses of paradigm entail structure:

Masterman (1970) finds twenty-one different ways in which Kuhn employs ‘paradigm’, not all of which are compatible with each other ... In a particularly insightful review, Shapere (1964) observes that there is far more to the notion of the paradigm ...:

... The term ‘paradigm’ thus covers a range of factors in scientific development including or somehow involving laws and theories, models, standards, and methods (both theoretical and instrumental), vague intuitions, explicit or implicit metaphysical beliefs (or prejudices). In short, anything that allows science to accomplish anything can be a part of (or somehow involved in) a paradigm.

(Suppe 1979, pp. 136-7)

That is, the term paradigm, at least as initially used by Kuhn and widely used by others, refers to various notions, many of which are structures - composite bodies (structures) of laws, theories and patterns of beliefs and activities - and is criticised because of its inherently vague structure. Kuhn’s later formulation of paradigm was more explicit about its structural characteristic.

Among the Weltanschauungen analyses, Hanson’s approach has also been influential in establishing the notion that observations are theory-laden. Hanson’s account characterises two distinguishing notions of structure. First, he argues that facts are stated in, and therefore tied to, language:

As such, the ability to apprehend facts ‘is of a piece with Tycho and Kepler seeing different things at dawn’, which is to say that using language with different meanings results in their seeing different things and also determines which facts they can easily apprehend.’ (Suppe 1979, pp. 158-9)

Thus Hanson argues that meanings are dependent on the context of a conceptual pattern, so a term can have a different meaning in a different conceptual pattern. The characteristic structures of scientific language are discussed in section 4.5 below. Terms used in explanations are context-dependent in this way, but not terms used for sense data. On Hanson’s account, then, observations are theory-laden, not theory-independent; accounts of theory-laden-ness, including Suppe, typically illustrate this with optical illusions where a single diagram can be interpreted in two or more ways. Thus scientific theories - and in this sense laws also - are structured in the sense that they account for observations as being structured: observations are sense data that are selected and arranged or composed - structured - by the mind. The second notion of structure in Hanson’s account is his claim that, contrary to the RV rejection of discovery as a psychological or historical
notion, there is a logic of discovery somewhat like Pierce's notion of abduction\textsuperscript{4}. While Suppe disputes that Hanson's retroductive reasoning is a logic, it is a pattern of thought or argument that, like induction and deduction, derives its meaning partly from its particular structure. Hanson argues that the reasons for accepting a particular hypothesis, which are reasons for thinking it true, are not the same thing as reasons for suggesting one hypothesis rather than other hypotheses, which are reasons for thinking it to be plausible. The order is to begin with some surprising phenomena, then to suggest that such phenomena would not be surprising given an appropriate hypothesis: therefore there is good reason to propose that hypothesis as an explanation for those phenomena. This relies on the theory-laden nature of observation and facts, for both are shaped by the conceptual organisation. Suppe, writing in 1977, sees this as a criticism of Hanson's account, but the theory-laden-ness of observations is widely accepted as part of the range of post-positivist accounts of observation in metascience (Boyd, Gasper & Trout 1991; Callon 1995).

**Post-positivist concerns with theories**

From the extensive post-positivist literature on scientific theories, including structures of theories, there are several other matters that show that theories remain central to characterising science. One is the challenge to the notion that theories are structures of objective knowledge. Some post-positivist characterisations of science argue that scientific theories are purposive constructs that embody ideologies, and can and should be analysed as such. They arise from several concerns: the actual rather than idealised construction of theories; the theory-laden-ness of observations and selection of facts from sense data; and broader notions of scientific purpose, as discussed in the companion chapter on purpose. The present thesis interprets such characterisations as combinations of dimensions, such as structure, belief system and purpose; examples of such multidimensional characterisation are given in section 3 of the Chapter 9.

**Under-determination of theories**

Another is the notion of *underdetermination of theories*. According to many popular characterisations of science, including naive verificationism and falsificationism, a theory is straightforwardly accepted or rejected according to whether it is verified or falsified by experimental (empirical) evidence. However, according to what is sometimes known as the Duhem-Quine thesis, scientific theories are not simply determined - accepted or

\textsuperscript{4} This is discussed in Appendix B.5 on activity.
rejected - by experimental evidence\(^5\). Rather, the available evidence can typically support more than one theory, which leads to problems about deciding between more than one theory claiming experimental support:

It is often our position that several theories are compatible with the available evidence: we then hope that more evidence will resolve the matter. The underdetermination of theory by evidence holds that logically incompatible theories may fit all possible evidence. Alternatively, there may be pairs of empirically equivalent theories which, while not contradicting each other, use radically different theoretical notions. Examples of such underdetermination have been proposed which embarrass empiricist philosophers (Quine 1990) who must either deny that such theories are in competition or find an empirical basis for preferring one of the pair. (Hookway 1992, p. 517)

Not surprisingly, the responses to this issue have been significant in influencing characterisations of science. One response has been to point out that this doctrine can lead to a relativism that undermines the very authority of science. In his discussion of pragmatism and science, Roger Trigg has commented that underdetermination of theory can be argued towards an extreme relativism that opposes traditional notions of scientific authority:

Without any metaphysical underpinning there is in fact nothing to agree about, nothing to constrain and guide us in our pursuit of truth. It is no wonder that practices are thought to shift arbitrarily. The very concept of truth becomes problematic. It used to be widely accepted that any belief or statement must be either true or false. This has become doubted, so that many would reject this so-called law of the excluded middle. Joseph Margolis sees in this rejection one of the main signs of relativism. He suggests that 'any doctrine counts as a form of relativism if it abandons the principle of excluded middle or bivalence ... or restricts its use, so that, in particular sectors of inquiry, incongruent claims may be validated (1991, p. 17). This is admittedly a weak form of relativism, but it does have large implications. It suggests that there is nothing against which different claims can be measured. In the case of science, it would suggest that our theories are under-determined by the world, or, worse, there is no sense in conceiving of one world independently of our theories. It suggests that there is no invariant order built into the structure of things. The world cannot be known by us, or, in Margolis' words, it is 'cognitively transparent'. This leads to the view that conceptions of real structures are at least as much the product of our society as of any world. This in turn should make cultural diversity unsurprising and leaves us with historical change as brute fact. (Trigg 1993, pp. 54-5)

Of course, the present thesis has already mentioned a number of (particularly post-positivist) views that do argue against the 'excluded middle', that notions such as truth

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\(^5\) This notion of under-determination is also called the Duhem-Quine principle. It asserts that no one single factor is enough to explain the closure of a controversy or the certainty acquired by scientists. This principle forms the philosophical basis of most social history of sociology of science. (Latour 1987, p.260)
can be contingent and not absolute. Thus another response has been to embrace the implications of underdetermination of theories:

[T]he natural sciences ... are underdetermined by facts, since no theory can be supported unequivocally by a finite collection of experimental results. Therefore if consensus is reached on a theory, it is not explained by facts alone but by the social conventions and common institutions shared by the members of scientific community. (Lynch 1992, p. 223)

That is, theories are indeed underdetermined by experimental evidence, and a moderate externalist response is that we therefore need to account not only for experimental evidence but also for other factors used in negotiating the outcome. Latour has been influential in encouraging others to re-examine actual laboratory practices. As discussed in Appendix B.5, there is a substantial body of literature that argues that laboratory activities are a good deal more complex than simply applying logical criteria to experimental results. On the other hand, Ian Hacking has argued that the notion of underdetermination of theories misses the point:

Duhem’s doctrine [was] that a theory inconsistent with an observation can always be saved by modifying an auxiliary hypothesis, typically a hypothesis about the working of an instrument such as the telescope. His was a thesis about thoughts; like most philosophers of theory he did not reflect on how we change not only our ideas but also the world. His doctrine, especially for those who read Quine, is taken to imply the underdetermination of scientific knowledge. When properly extended, it has quite the opposite effect, of helping us to understand how the world and our knowledge of it are so remarkably determinate.

Duhem said that theory and auxiliary hypotheses can be adjusted to each other; he left out the whole teeming world of making instruments, remaking them, making them work, and rethinking how they work. It is my thesis that as a laboratory science matures, it develops a body of types of theory and types of apparatus and types of analysis that are mutually adjusted to each other. They become what Heisenberg (e.g., 1948) notoriously said Newtonian mechanics was, ‘a closed system’ that is essentially irrefutable. They are self-vindicating in the sense that any test of theory is against apparatus that has evolved in conjunction with it - and in conjunction with modes of data analysis. Conversely, the criteria for the working of the apparatus and for the correctness of analysis is precisely the fit with theory. (Hacking 1992, p. 30).

That is, Hacking argues that theories are considered to be underdetermined only if we restrict our characterisation to the cognitive context. If we consider also the physical context - the apparatus - and belief system, then we find a mutually supporting set of theories that accounts for all these characteristics. That is, theories, experimental results, our beliefs about the phenomena and our beliefs about the working of the apparatus make sense when considered together, and fail to make sense when taken, artificially, in isolation.
c) **Scientific disciplines as structures**

We mentioned at the beginning of this section (4.4) an incomplete overlap between the two notions of *scientific disciplines* as structures of knowledge and organisations. We will mention here the notion of disciplines as knowledge structures, and defer discussion of organisational structures and overlap between the two until section 4.5, below. A historical notion of disciplines as structures of knowledge is given in Table B.4.2, below. Needless to say, there is no single, accepted structure: some current disciplines are historically recent, while many knowledge structures that in the past were characterised as science would not be seen so today. For example, we have seen above that there have been several attempts, but none successful, to discern a common structure for theories in different scientific disciplines. Likewise a physiologist, a biochemist and a biophysicist could find themselves working together on, say, a project concerning neurotransmitters. Thus it is at the same time a commonplace to list disciplines such as physics, chemistry, biology and geology (frequently in that order) as traditional cognitive fields or disciplines of science, and to recognise that during the twentieth century science became characterised increasingly by blends of existing disciplines and the emergence of new disciplines. Historically, astrology is listed as a discipline alongside astronomy, for example, but is no longer accepted as a science by the mainstream scientific community today.


d) **Other cognitive structures in science**

Finally, we will mention briefly that there are notions of knowledge structures which, while not as widely used as *law, theory or discipline*, use the notion of structure in other ways. For example, Shapere has argued that a useful construct is scientific *domains*:

[A scientific domain is] a number of items of information or putative facts (perhaps including accepted laws and theories) which come to be associated together as a body of information having the following characteristics: the association is based on some well-grounded, significant, relationships between the items of information which are suggestive of deeper unities among the items; there is something problematic about the body so related; the problems are important; and, usually, the science is 'ready' to deal with them. And Shapere and his associates have been able to demonstrate that for a wide variety of cases ... scientific domains do pose problems in this way, and, possibly aided by a certain amount of background information or knowledge, rationally suggest certain types of theories as likely candidates for explaining the underlying unities of the domain information ... Minimally, these findings indicate that from its most primitive to its most advanced stages, there is a rational basis for theorising. Thus, contra Lakatos, there is a rationality to theorising even in the primitive 'immature' stages of science. (Suppe 1979, p. 667)
That is, Shapere claims that the very structural arrangement of items in a domain, together perhaps with appropriate background information, 'rationally poses or raises problems' (Suppe 1979, p. 686). On Shapere's analysis, a domain is not the same as a scientific field, which is a much broader concept of cognitive structure. Nor is it the same as a discipline, which is a broader term that can include organisational factors, as we have seen. To put this in a broader perspective, Callon's (1995) meta-analysis shows that attempts to delineate domains or fields vary according to the analytical approach taken; further, since some of these argue that rationality is constructed and negotiated, they will deny an underlying rationality as the basis for structures.
Organisational structures

Having mentioned the overlap between disciplines as both structures of knowledge and of organisations, we turn now to organisational structures that characterise science. Clearly, this overlap arises because teaching, research and learning in a discipline requires the organisation of people and resources.

Historically, the overlap between knowledge and organisational structures arose largely from the organisation of study in the early universities, noting that science as we now characterise it did not exist then. From the beginning the first universities were organised around disciplines of study, and from which derives the very term university:

The first university (or quasi university), at Salerno (now Italy) in the ninth century, was a school of medicine; and the second, at Bologna around AD. 100, was chiefly a school of law (civil as well as canon law); they included secular as well as ecclesiastic students. The transitions of schools to universities involves the formation of a community or federation of teachers or students or both into a ‘whole’ (universus) body, a universitas magistrorum or a universitas scholarium or a universitas magistrorum et scholarium. These bodies had the character of guilds, chartered by ecclesiastic and/or secular authorities, usually the pope, the emperor, the king. The students’ communities were often formed along national lines, so-called ‘nations’, confederations of aliens on foreign soil, with privileges granting them various rights ... (Machlup 1971, in Machlup 1982, p. 121)

By the year 1200, there were six universities in Europe established without a papal bull or imperial charter; by the fourteenth century the number had grown to fifty five. The curriculum - meaning the knowledge structure - was reasonably common across the institutions, and the organisational structure reflected this:

Even if some of the mediaeval universities began as professional schools - faculties of theology, law, or medicine - they usually added a fourth, a faculty of philosophy. All studies, professional or philosophical, were preceded by years of study in the liberal arts, divided into two curricula, the trivium, consisting of grammar, rhetoric, and dialectic (logic), and the quadrivium, consisting of music, arithmetic, geometry, and astronomy. The professional schools considered themselves the ‘superior’ faculties vis-à-vis the faculty of philosophy. Philosophy, in its early scope, consisted of ethics, physics, and metaphysics. Some universities actually began as faculties of philosophy. The first of these was the University of Paris, which emphasised from the start the study of logic and philosophy, regarded as the ‘science of the sciences’. (Machlup 1982, pp. 122-3)

These examples are given not just to show that knowledge and organisational structures have characterised science historically, but to give some idea of the antiquity of some notions of structure in science. Machlup gives a good deal more historical detail than is necessary here, but simply to emphasise the influence of these traditions of
structure, we should note that studies in Greek ‘remained an entrance requirement at Oxford and Cambridge until the 1920s, and Latin, until around 1960’ (Machlup 1982, p. 139). Of course, the traditional four faculties had long gone by that time, and in any event there was much greater variation between university structures - meaning the number and names of faculties and what they taught - from the nineteenth and into the twentieth centuries, when compared with the mediaeval universities.

Organisational structures do not always overlap because, increasingly so in the twentieth century, there is more than one way, and more than one reason, to deploy resources for education and research. For example, Redner (1987) points to a number of arguments in the literature - of both scientists and sociologists of science - that the new, hybrid disciplines reflect more their organisational basis as against the traditional, cognitive basis of the pre-existing disciplines:

Thus in the social sciences as in the natural sciences, indeed the whole field of knowledge (Wissenschaft), the tendency has been for changes in technique and social organisation to exceed those in pure cognition.

Perhaps the single clearest statement summing up the nature of the multiple changes in post-war science is one from Harvey Brooks:

The growth of science in the post-war era has been characterised by the spectacular expansion of hybrid disciplines such as geophysics, geochemistry, biochemistry, chemical physics, computer science and systems analysis. Techniques such as radiocarbon dating, the use of radioactive tracers, paper and gas chromatography, microwave and nuclear resonance spectroscopy, and X-ray diffraction have spread rapidly. Interdisciplinary subjects such as oceanography, atmospheric sciences, and space science draw on all the more classical disciplines, and it is difficult to tell at what point they do or should be considered disciplines in their own right. Whole areas of research often move from one discipline to another. For example, atomic spectroscopy, which used to be a major branch of physics, has now moved almost entirely into astronomy. Similarly, molecular spectroscopy has largely moved from physics into chemistry. The study of cosmic rays has largely moved from physics into a branch of space science, the theory of low energy nuclear reactions has become an important part of astrophysics. It becomes increasingly difficult to define a discipline except by the organisational framework within which it is pursued - for example, physics is what is done currently in academic physics departments (Brooks 1968, p. 57)

Noteworthy in this account is the clear distinction between the classical disciplines, or the idea of a discipline in Classical science, and disciplines in contemporary science defined largely by their ‘organisational framework’. The extract clearly indicates that in post-war science a reorganisation has taken place: specialities have moved from one discipline to another or specialities from different disciplines have fused to form a new hybrid. The spread of instrumental techniques and the development of new machines and their shift from one speciality to another have also been crucial for this reorganisation. The prime importance of organisation is emphasised further when Brooks proposes criteria for the classification of research ‘in terms of the primary purpose of the institution in which it is conducted or of the institution’s organisational subdivision’ (ibid. p. 59) (Redner 1987, pp. 18-19)
This rather lengthy passage from Redner clearly characterises science by the organisation of its disciplines. Redner does not deny that disciplines have a cognitive basis, but is clear that, drawing on Brooks's argument, increasingly it is inadequate to account for disciplines in post-war science. The present thesis interprets this characterisation as concerning organisation, context and purpose, firstly, and secondarily knowledge. As another example of the interdependence of cognitive and organisational structures, in 1996 the University of Wollongong offered courses leading to a Bachelor of Science degree in both the Faculty of Science and the Faculty of Health and Behavioural Sciences, whereas the University of Western Sydney, Macarthur offered the Bachelor of Science degree in the Faculty of Business and Technology, which also offered degrees in business, commerce, technology management, and design and technology (UAC 1996 Guide). The contents of those science courses reflects the orientations of the faculties that offer them.

Despite the foregoing argument and the public visibility of disciplines, departments, faculties and universities as organisational structures of science, a strong case can be made that from about the middle of the twentieth century the more significant notion of structure is of science as institutions. Science as an institution embodies two senses of structure: one is some sense of a largely internal structure, which is not just faculties but the hierarchical relationships of power and influence, resourcing and so forth; the other is in some sense an external notion of structure, by which we characterise the structural relationships of science with governments, industries, the military, and other social groups. Both of these notions are found in the summary statements:

[There are] three basic aspects of all scientific work: the organisational, instrumental and cognitive - in short, people, machines and ideas. These can be ranked in this order of importance because the changes that brought about the contemporary epoch of science can be graded with this weighting scale. The most crucial changes took place in the organisation of science, that is, in the socio-political system and institutional arrangements under which science is produced.
(Redner 1987, in summary statement 118)

The term 'science' [can be used] to indicate ... an institution or set of organisational arrangements designed for educating and accrediting scientists, approving or discrediting scientific conclusions, and for protecting the interests of the scientific estate ... [and] an ideology, that is, an organised way of thinking about reality which serves to maintain and perpetuate structures and patterns of social domination and subordination.
(Kenny 1988, in summary statement 14)

[S]cience and technology [are] human, social, political institutions with complicated histories and relations to the rest of society.
(Schuster 1993, in summary statement 81)
The development of science organisations is not a recent one. For example, the Scientific Revolution is characterised partly by the emergence of scientific institutions like the Royal Society:

[N]early all the main branches of modern science were established in the seventeenth century, and a great deal of fundamental work from this period has survived, whereas by far the greater portion of earlier work has been quite superseded. Moreover, the seventeenth century also saw the foundation of the scientific movement as a social system, with a character that has, in some measure, lasted till the present day. For example, some of today’s most prestigious scientific societies and journals were established in the seventeenth century. (Oldroyd 1989, p. 49)

Thus the Royal Society of London, founded in 1662, and the Académie des Sciences (later the Institut de France), founded in 1666, became the model for many later academies across Britain, Europe and their colonies (Emerson 1990). It was the academies, and later, other bodies, that gave a structural identity to science, thereby pooling talents, marshalling and deploying resources and serving as a focus of identity and articulation with other organisations in society, notably governments and industries. Much of the literature addressing science in society is based on this institutional character of science, because the traditional concern in philosophy with knowledge and a rational understanding of (mental) scientific activities does not account for the greater part of science-society interactions. Much of this literature emphasises context, because it addresses the character of science as an institution in relation to other institutions in society, but the structural nature of science - as an institution, in comparison with other institutions, and as part of larger structural arrangements - is also characteristic. In their review of the literature addressing science, government and the politics of knowledge - essentially a contextual issue - Cozzens and Woodhouse (1995) characterise this interplay by structural arrangements, notably institutions, organisations, power relationships and authority structures. They argue three positions from this field of research, namely politics and the shaping of knowledge, scientific expertise and society, and science and business:

[First is] the claim that research knowledge is a product of politics. The authority structure of the funding system - who participates in it, in what network of power relationships - is a dominating influence. Because most research is supported with government funding, distributed through agencies established and maintained through political negotiation, the balance of knowledge among fields is a political product. Moreover, the assumptions and worldviews of science are shaped by expectations conveyed through the funding system and by the access it allows to various social groups. Industry, bureaucracy, and the organised public all play roles ...

[Second is] another major facet of the structure of authority, that is, the role of expertise in policymaking. In theory, there is no necessary contradiction
between government's use of expertise and its responsiveness to public concerns. In actuality, conflicts abound. Professional scientists and their allies often win substantial autonomy to promote knowledge and resource claims in ways that advantage them at the expense of other equally legitimate social interests. Among other issues considered in this section is the extent to which environmental, consumer, and other public interest organisations serve as countervailing forces to the knowledge/power alliance.

[Third], science stands in special relationship to industry, which is itself a source - perhaps the major source - of negotiating power in the modern state. [We will attempt] to situate the actions of science elites, their allies, and their potential or actual adversaries within the structural setting of market-oriented societies. When governments leave the development and distribution of technologies to private corporations, publicly funded research serves primarily as an inducement to the private sector to perform this function, and only secondarily as a form of public choice of knowledge or technology. Given the current structure of influence around science, research is much more likely to be pulled in directions chosen by industry than to pushed toward democratically chosen ends, no matter how open the priority-setting process of government becomes. Thus democratic control of science depends ultimately on democratic control of technology. (Cozzens & Woodhouse 1995, pp. 534-5)

That is, the organisation of science is a meaningful way of characterising science to account for the successful negotiation of authority. First, this field characterises the political nature of knowledge in terms of power and authority structures by which resources are (politically) negotiated. Second, the public negotiation of scientific authority, as in policy decisions and science-based public disputes, is characterised by organisations (including organised science) acting politically. Third, the need of business for scientific knowledge and expertise as a resource is an established influence on science against which the relative influences of government and citizen needs are weighed: it is characterised by the relative influences of science, government, industry and citizen groups as institutions. It is by this structural characteristic that we understand the relative impotence of citizen groups when seeking to dispute scientific claims by organised science groups within universities, government agencies or industry. True, lack of knowledge (cognitive expertise) and skills (methodological expertise) are factors. However, these critiques point to political reasons for this, such as the (lack of) access of citizen groups to the planning of studies, to the classified results of studies, and sometimes contentious character of 'scientific' results once they have been opened to scrutiny.
4.6 Language structures

There is another sense in which we characterise science by the structured arrangements of components, and that is that we recognise science by characteristic structures of language. There are weak and strong versions of this argument. The weaker, or less demanding, argument is that to express the particular concepts, relationships and precision of argument found in science, we construct scientific language in particular, or characteristic, ways. Better known examples of this are the use of passive voice and the third person. The stronger argument is that science is not represented merely by language as a technology, but that science is language. The strong version holds that we shape or construct our ideas with language, and that we cannot know anything other than as expressed in language; we therefore understand science only to the extent we understand these uses and structures of language. The two approaches could be labelled as expressing meaning (weak) versus making meaning (strong) (Halliday & Martin 1993, p. 23). We will sketch both the weak and strong versions here.

The weaker argument is relatively uncontentious, and essentially describes the characteristic structures and uses of scientific language. Halliday and Martin (1993) have argued that the language of science is characterised both by a technical vocabulary and the wording, although both need not be present together in any particular example: the present thesis interprets the vocabulary, and indeed all units of text or discourse, as elements of a structure, and the wording is of course the arrangement or structure itself. The technical vocabulary is self-evident: terms such as atom, chemical equilibrium and Boltzman's constant characterise science just as any field is characterised by its particular vocabulary of jargon. Less evident to those not familiar with the linguistic analysis, and indeed often simply assumed by those who are science-educated, is the wording of science. The notion of structure can be shown easily in examples that are free of jargon words:

It is not difficult ... to find passages of wording without many technical terms which are still very clear instances of scientific writing ... [T]he following extract from Scientific American contains hardly any technical terms:

Our work on crack growth in other solids leads us to believe that the general conclusions developed for silica can explain the strength behaviour of a wide range of brittle materials. The actual crack tip reactions appear to vary from material to material and the chemistry of each solid must be considered on a case-by-case basis. (Michalske & Bunker 1987, p. 81)

Of course, technical terms are an essential part of scientific language; it would be impossible to create a discourse of organised knowledge without them. But they are not the whole story. The distinctive quality of scientific language lies in the lexicogrammar (the 'wording') as a whole, and any response it engenders in the
reader is a response to the total patterns of the discourse. (Halliday & Martin 1993, pp. 3-4)

The patterns or structures of scientific discourse are learned and used by those trained in science, even when they are not familiar with the grammatical labels for these structures; the structures become familiar and make sense - they are meaningful - because of this use. Scientific English is a variety of English - like scientific Chinese is a variety of Chinese - that can be difficult to make meaningful just as English can be difficult when learned as a second language:

[Scientific English] is English with special probabilities attached: a form of English in which certain words, and more significantly certain grammatical constructions, stand out as more highly favoured, while others correspondingly recede and become less highly favoured, than in other varieties of the language. This is not to imply that there is one uniform version of it, any more than when we talk of British English or Australian English we are implying that there is one uniform version of each of these dialects. Any variety of a language, whether functional or dialectal, occupies an extended space, a region whose boundaries are fuzzy and within which there can be considerable internal variation. But it can be defined, and recognised, by certain syndromes, patterns of co-occurrence among features at one or another linguistic level - typically, features of the expression in the case of a dialect, features of the content in the case of a functional variety or 'register'. Such syndromes are what make it plausible to talk of 'the language of science'. (Halliday & Martin 1993, p. 4)

These structures of scientific language began to emerge in the sixteenth and seventeenth centuries and so are one criterion by which we characterise the Scientific Revolution. Thus, for example, Francis Bacon, Thomas Hobbes and John Locke (following William of Ockham) reacted against the mediaeval tendency to ascribe ontologically real entities for the human categories represented by words. This is a belief about the nature of scientific language that continues to characterise science, and is called nominalism:

[Nominalism is] a deep-seated current in western thought distrusting the tendency of the names and classifications given to natural objects to acquire a life of their own, occluding natural reality ... During the Scientific revolution, nominalists such as Hobbes denied the verbal categories of Aristotelian/Scholastic science (such as 'essence' or 'quality') represented reality in Nature, or had explanatory power ... Baconian nominalism also called for a philosophy of work not words, i.e. one dedicated to using Nature for human benefit, not just understanding it. Seventeenth century science also followed a nominalist tack in demanding a plain and unrhetorical language of science, Nature as far as possible being translated into quantitative terms. Enlightenment scientific nominalism ... crystallised in the positivist developmental theory of scientific explanation, in which the age of empty verbal explanations (metaphysics) had been superseded by that of positivist accounts (causal explanations by law-like regularities). (Porter 1983a, p. 300)
That is, in the nominalist tradition the word or term is recognised as a label for an entity and not as the entity itself: merely labelling something is not an explanation of it. Thus the terms or units of text, being the components of the language structure, changed as some entities were abandoned and other, new, ones were identified.

However, the structure or wording itself also changed. Halliday and Martin (1993) have argued that the Scientific Revolution is also characterised by changes in the grammatical structure, and analyse a number of examples from Newton and others:

It is convenient to think of the new resources that came into scientific English (and other languages: for example, the Italian of Galileo) at this time as falling under these two headings, the lexical and the grammatical. The 'lexical' resources were highly visible, in the form of vast numbers of new technical terms; what was significant, however, was not so much the terms themselves as the potential that lay behind them. On the one hand ... they could be formed into systematic taxonomic hierarchies; on the other hand, they could be added to ad infinitum - today a bilingual dictionary of a single branch of a scientific discipline may easily contain 50 000-100 000 entries. The 'grammatical' resources was the constructions of nominal groups and clauses, deployed so that they could be combined to construe a particular form of reasoned argument: a rhetorical structure which soon developed as the prototypical discourse pattern for experimental science. Any passage of Newton's writings could be taken to illustrate these resources, both the lexical and the grammatical ... (Martin & Halliday 1993, p. 7)

Several of these grammatical structures characterise scientific English, and they are typically interdependent; the following account highlights some characteristic features according to Martin and Halliday's systemic functional linguistics (SFL) analysis (Halliday & Martin 1993, pp. 54-68). At the level of analysis with which we are concerned, there are two elements of interest: process (or verbal) elements, and naming (noun or nominal) elements.

**Nominalisation of verbal elements**

First, scientific English is characterised by the restructuring of verbal elements in non-scientific English into nominal (or noun) elements in scientific English. This can happen in a single piece of text: Martin and Halliday (p. 7-8) show examples, in a quote from Newton (1704), of verbs or adjectives early in the passage being later reworded as nouns or nominal elements:

(i) *will not be refracted enough*  
(refracted)  
becomes  
*for want of sufficient refraction*  
(refraction)  

(ii) *paint ... a confused picture*  
(confused)  
becomes  
*according to the indistinctness of this picture*  
(indistinctness)
Appendix B.4: Structure

(iii) those convex glasses becomes if the glass have a due degree of convexity

The initial version of each example presents the piece of discourse as new information; by rewording as a nominal element it is not presented as new, and can be ‘re-used as a given in the course of the succeeding argument’ (Halliday & Martin 1993, p. 8). In this way, processes become technical terms - objects rather than processes - and thus an accepted part of the technical vocabulary of the language. This process of nominalisation has been progressing ‘over the past four to six centuries’ somewhat as follows (Halliday & Martin 1993, p. 66):

1. Externally (relating nominalised processes to each other)
   from a happens; so x happens
   . because a happens, x happens
   . that a happens causes x to happen
   . happening a causes happening x
   to happening a is the cause of happening x

2. Internally (relating nominalised processes to our interpretation of them)
   from a happens; so we know x happens
   . because a happens, we know x happens
   . that a happens proves x to happen
   . happening a proves happening x
   to happening a is the proof of happening x

The latest of these steps, where the cause and the proof are nominalised, took place in the twentieth century. Thus the experiential content of language is shifted into nominal or name groups: both elements are structured as nominals. That is, the language structures of nominalisation tend to hide the assumptions in, and encourage the acceptance of, scientific argument. This is not to argue that nominalisation is or was a devious strategy necessarily. However, it is a rhetoric strategy of scientific and technical languages which needs to be understood if we are to understand scientific argument in, say, science journals. One reason is because nominalisation processes, such as those above given by Halliday and Martin, imply or assume that a causal relationship is established, which goes to the heart of what scientists seek to argue or refute.

Another reason is that nominalisation confers authority onto arguments, and for this reason it is also used in wider contexts, or more accurately, for wider audiences and purposes than just the expert peers of the researcher. It needs to be understood for this reason too. For example, Gieryn and Figert (1990) have shown that the NASA and MTI submissions to the commission investigating the 1986 explosion of the space shuttle
Appendix B.4: Structure

Challenger were characterised by highly technical language, including many acronyms and jargon terms unfamiliar to 'lay' audiences including scientists not working in that program. They argued that part of the reason for the space authorities using these structures was to confer authority to their argument and dissuade objection. Conversely, they argued, part of the reason why these opinions were rejected by the public, and some experts, was that a contradictory argument was put clearly in language understood by both expert and lay audiences.

Technical taxonomies

Second, the nominal elements form structures called technical taxonomies, which may be technological, methodological or theoretical categories:

In the natural sciences, technical concepts have little value in themselves; they derive their meaning from being organised into taxonomies. Such taxonomies are not simply groups of related terms; they are highly ordered constructions in which every term has a definite functional value. As Wignell, Martin and Eggins point out ... a technical taxonomy is typically based on two fundamental semantic relationships: 'a is a kind of x' (superordination) and 'b is a part of y' (composition). Thus in their example of climate, climate is divided into certain kinds, and is composed of certain parts ... [T]he first is an either/or relationship: 'every climate is either tropical or subtropical or ...'; the second is a both + and relationship: 'every climate is both temperature and solar radiation and ...' (We have to stretch the meaning of either and both here so that they are no longer limited to just two.) (Halliday & Martin 1993, p. 73)

Thus the nominal elements of scientific discourse derive much of their meaning from being structured as taxonomies of concepts. A related structural notion is that definitions are commonly constructed in an interlocking fashion, such that a single passage of text will define several terms that depend on each other for their meaning:

A circle is a plane curve with the special property that every point on it is at the same distance from a particular point called the centre. This distance is called the radius of the circle. The diameter of the circle is twice the radius. The length of the circle is called its circumference. (Example quoted by Halliday & Martin 1993, p. 72)

In this example, circle, centre, radius, diameter and circumference are all part of a series of interlocking definitions: circle, centre and radius are mutually defining and assume the prior definition of distance and plane curve; diameter and circumference are defined in terms of the first three. These structures - technical taxonomies and interlocking definitions - are typical of scientific discourse: that is, they are characteristic of it.

Repackaging meaning

Third, the nominal elements summarise and package the representations of processes. This is related to the process of nominalisation: the nominal elements become
Appendix B.4: Structure

the units for the entire semantic content or meaning. Take the following example, given by Halliday and Martin (1993, p. 62):

According to this theory, all the operations of electricity depend upon one fluid sui generis ... dispersed through the pores of all bodies, by which the particles of it are as strongly attracted, as they are repelled by one another.

When the equilibrium of this fluid in any body is not disturbed; that is, when there is in any body neither more nor less of it than its natural share, or than that quantity which it is capable of retaining by its own attraction, it does not discover itself to our sense by any effect...

The equilibrium being forcible disturbed, the mutual repulsion of the particles of the fluid is necessarily extended to restore it.

Nominal elements can be a noun, as in equilibrium, or a noun group (nominal group), as in the equilibrium of this fluid in any body. Nominalisation produces three effects of interest to the present argument. First is backgrounding, where the nominalised processes become the subject or theme of the sentence. Thus the abstract technical term equilibrium becomes the head of the nominal group the equilibrium of this fluid in any body and is established as a thing that can be changed and restored. Second is foregrounding, where the verb is left ‘to express the relationship between these nominalised processes’ (Halliday & Martin 1993, p. 63). Thus, in the earlier construction, the news is that the particles are repelled, and the theme is the particles. Once this is no longer news, it can be assumed and the news becomes the restoring of the equilibrium. The only means to do this is by nominalisation: are repelled by one another becomes mutual repulsion; the verbal group is exerted ‘simply tells us that it happens’ (ibid.). Third, this leads to the use of passive voice. In scientific English, the agent or actor of a process is not always the subject or theme of the sentence, as we have seen. Where this is the case, the passive voice is the appropriate construction, as Halliday and Martin comment in relation to a passage from Newton:

Such descriptions often come in the passive, as in the Sun’s Beam which was propagated ... Note that these have nothing to do with the suppressed person passive favoured by modern teachers and scientific editors, which came into fashion only late in the nineteenth century. They are simply the passive in its typical function in English: that of achieving the balance of information the speaker or writer intends - often describing the result of an experimental step, where the Theme is something other than the Actor in the process (the Ray ... is shatter’d). If the discourse context requires Actor as theme Newton displays no coyness about using I. (Halliday & Martin 1993, p. 58)

This much, as we have said, is relatively straightforward as an analysis of language being used to express meaning, and an example of characterising science by structure.

The more contentious issue is whether the weak (expressing meaning) or strong (making meaning) interpretation is made. An example of the so-called weak version would be where an account speaks of the language of science: the language expresses
meaning. Even though he treats language as part of a larger issue, Bronowski (1978) also interprets language as essentially expressing meaning - describing Nature - rather than the language as the construction itself. He gives the example (pp. 42-3) of Mendeleev's idea of the periodic table, who, by inductive reasoning, found regularities or patterns in chemical elements if they were arranged in order of their atomic weight. The importance was that, aside from being confirmed, 'it turned out that this regularity meant something. It represented a real law of nature' concerning the structure of atoms. Induction 'in the Baconian sense had only foreshadowed' a 'profound explanation, a law of nature'. The similarity, the induction, 'pointed to an explanation' (Bronowski 1978, p. 43):

(S)cience ... organises these appearances, the messages that come to us through the senses, and organises them in some way which gives them a structure. The best analogy that can be made to that structure is to say that science is a language which has these kinds of units in it. In The Identity of Man (N.Y., Doubleday/Natural History Museum, 1971, p. 42) I wrote:

Science is not so much a model of nature as a living language for describing her. It has the structure of a language, a vocabulary, a formal grammar, and a dictionary for translation. The vocabulary of science consists of its concepts all the way from universal gravity and the neutron to the neuron and the unconscious. The rules of grammar tell us how to arrange the concepts in sensible sentences - that atoms can capture neutrons, for example, and that heavy atoms when they split will release them. And the dictionary then translates these abstract sentences into practical observations that we can test in the everyday world: for example, in the damage that neutrons do when plutonium is split.

It is my view that we analyse the world in exactly the same way that science does, and we do that from the moment we start being the human animal. We analyse our experience in that way. At the time that we learn language, we match the analysis of experience with the analysis of what our parents say to us, and finally we analyse natural phenomena from which we control the messages of nature ... (Bronowski 1978, pp. 45-7)

Thus although Bronowski characterises science as language, he speaks of analysing our experiences, and matching these analyses at the time that we learn our language. Contrast this with the constructivist view in following extracts:

Language is not a superstructure on a base; it is a product of the conscious and the material impacting each on the other ... Hence language has the power to shape our consciousness ... [S]ince language evolves out of the impact between the material and the conscious modes of being, it follows that as material conditions change the forms given by language to consciousness also change. (Halliday 1990, p. 11)

The whole [grammatical] configuration is an immensely powerful resource for the semiotic construction of reality. (Halliday & Martin 1993, p. 64)

That is, it is the structural character of the grammar - through devices such as nominalised processes - that shapes our ability to construct our notions of reality. This is a contentious point in the literature, as shown by constructivism being but one of several current views
in metascience. For example, other arguments hold that not just material conditions but consciousness also changes, that forms are not only given by language by an external reality, and that forms are not only given by language but to language by perceptual inputs. These matters are taken up in Appendix B.5 and the companion chapter on activity, where they are discussed in relation to observation and language and which comes first.
### Table B.4.1

Examples of characterisation of key metascientific viewpoints by structure

<table>
<thead>
<tr>
<th>Author</th>
<th>Viewpoint</th>
<th>Examples of reference to structure</th>
<th>Identified in the work of</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suppe 1973, 1979</td>
<td>Received View</td>
<td>Scientific theories are <em>logical structures</em> of concepts and propositions.</td>
<td>Carnap</td>
</tr>
<tr>
<td></td>
<td>sceptical descriptive</td>
<td>The is no underlying <em>universal structure</em> of scientific theories; different <em>structures</em> reflect different purposes.</td>
<td>Achinstein, Rapoport</td>
</tr>
<tr>
<td></td>
<td>Weltanschauungen (world view)</td>
<td>The <em>structure of theories</em> arises from a <em>Weltanschauungen</em>.</td>
<td>Bohm, Feyerabend, Hanson, Kuhn, Popper, Toulmin</td>
</tr>
<tr>
<td>Bhaskar 1983</td>
<td>empiricism</td>
<td>Experiences analysed inductively as laws; deductive <em>hierarchy of propositions</em> based on inductive facts</td>
<td>Francis Bacon, Berkeley, Hobbes, Hume, Locke, Mach (positivism), Mill, Russell, Vienna Circle (logical empiricism)</td>
</tr>
<tr>
<td></td>
<td>idealism</td>
<td>Reality is <em>structured or composed</em> according to the structure of minds or ideas; reality exists independently of us, but our knowledge of it is <em>structured</em> by the human mind (Kant)</td>
<td>Berkeley, Fichte, Hegel, Hume, Kant, Plato, Schelling</td>
</tr>
<tr>
<td></td>
<td>realism</td>
<td>Statements about reality (a) cannot be tested in isolation (Duhen), (b) are a <em>network</em> whose attachment to reality is theory-dependent and mutable (Hesse) Competing theories are alternative descriptions of the same world</td>
<td>Aristode, Bachelard, Bhaskar, Duhen, Feyerabend, Hanson, Harré, Hesse, Hume, Kant, Koyré, Kuhn, Plato, Popper, Putnam, Quine</td>
</tr>
<tr>
<td>Nussbaum 1989</td>
<td>rationalism</td>
<td>Proven or confirmed knowledge is <em>structured</em> by the power of the intellect</td>
<td>Descartes, Kant, Plato</td>
</tr>
<tr>
<td></td>
<td>empiricism/ positivism</td>
<td>Proven or confirmed knowledge is <em>structured</em> by the evidence of the senses</td>
<td>Bacon, Comte, Hempel, Hume, Locke</td>
</tr>
<tr>
<td></td>
<td>constructivism</td>
<td>The best current knowledge is <em>structured</em> according to (a) inner disciplinary criteria (rational, logical, empirical) (b) outer disciplinary criteria (social-psychological, historical)</td>
<td>(a) Popper, Lakatos, Toulmin, partly Kuhn (b) Kuhn, Toulmin, partly Lakatos</td>
</tr>
<tr>
<td>Author(s)</td>
<td>Type</td>
<td>Description</td>
<td>References</td>
</tr>
<tr>
<td>-------------------</td>
<td>----------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Boyd, Gaspar and Trout 1991</td>
<td>post-positivist consensus comprising (a) post-positivist empiricism, (b) neo-Kantian constructivism, and (c) scientific realism</td>
<td>Scientific methodology and knowledge are theory-dependent.</td>
<td>(a) Partly Popper (b) Hanson, Kuhn (c) Boyd, Goodman, Kripke, Putnam, Quine</td>
</tr>
<tr>
<td>Pickering 1992</td>
<td>scientific knowledge as objective (logical empiricism)</td>
<td>Scientific practice is characterised by disciplinary structures and boundaries.</td>
<td>Kuhn, Feyerabend</td>
</tr>
<tr>
<td></td>
<td>scientific knowledge as relative to culture</td>
<td>Scientific knowledge/institutional structures model existing structures.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>scientific knowledge as relative to interests (sociology of scientific knowledge - SSK)</td>
<td>Scientific structures are negotiated by actors.</td>
<td>Barnes, Bloor, Callon, Cartwright, Collins, Garfinkel, Gilbert, Knorr Cetina, Latour, Law, Lynch, Mulkay, Shapin, Woolgar</td>
</tr>
<tr>
<td>Callon 1995</td>
<td>science as rational knowledge</td>
<td>The cognitive or disciplinary organisation of science arises from scientific statements, and constrains the social organisation of science. Model 2 applies here.</td>
<td>Hesse, Holton, Popper</td>
</tr>
<tr>
<td></td>
<td>science as competitive enterprise</td>
<td>The cognitive/disciplinary organisation of science is encouraged by the social organisation of science (internally); external boundaries are clear, beyond which scientific structures break down.</td>
<td>Althusser, Ben-Cole, David, Freudenthal, Hull, Merton, Popper</td>
</tr>
<tr>
<td></td>
<td>science as sociocultural practice</td>
<td>Organisational and institutional forms are only moderately significant; more significant are social structures, such as master-disciple relationships. Boundaries are constructed by actors.</td>
<td>Bachelard, Barnes, Collins, Fleck, Knorr-Cetina, Kuhn, Mulkay, Pinch, Ravetz, Rudwick, Schaffer, Wise, Wittgenstein</td>
</tr>
<tr>
<td></td>
<td>science as extended translation</td>
<td>There are two perspectives on organisation: (1) the overall dynamics of networks of actants; (2) the internal management of the elements of networks.</td>
<td>Arnaan, Callon, Foucault, Knorr Cetina, Latour, Pickering, Wise, Woolgar</td>
</tr>
</tbody>
</table>
## Table B.4.2

### Historical examples of knowledge structures

<table>
<thead>
<tr>
<th>Name</th>
<th>Headings of main categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aristotle</td>
<td>knowledge 1. a priori 2. a posteriori knowledge 1. discovering and learning 2. proving and demonstrating knowledge 1. theoretical 2. practical 3. productive science 1. theoretical 1.1 speculative thinking (physics) 2. empirical 2.1 inductive generalisations (biology) physics causes 1. material - as in, of what something is made 2. formal - as in, how something was made 3. efficient - as in, the plan or pattern of something 4. final - as in, the intention of the maker substances 1. first substances - as in Socrates 2. universals - as in Socrates is a man 3. coincidentals - as in quality, quantity, relative, etc changes 1. generation and destruction of substance 2. motion - change of category of quality 3. motion - increase or decrease of category of quality 4. motion - locomotion in category of place physics motions 1. natural 2. violent 3. voluntary biology taxonomy 1. botany 2. zoology theoretical philosophies 1. physics 2. mathematics 3. theology mathematics 1. universal mathematics 2. geometry and astronomy</td>
</tr>
<tr>
<td>Porphyry</td>
<td>Substance as the most general category, divided dichotomously like branches of a tree, until the unit is a single type. Units at any intermediate level can be combined as genera, or divided as species.</td>
</tr>
<tr>
<td>Aurelius Augustinus (Saint Augustine) (354-430)</td>
<td>Variously between 5 and 8 of this list of disciplines:</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td>1. Grammar</td>
<td>(later the trivium)</td>
</tr>
<tr>
<td>2. Dialectics</td>
<td>(later the trivium)</td>
</tr>
<tr>
<td>3. Rhetoric</td>
<td>(later the trivium)</td>
</tr>
<tr>
<td>4. Arithmetic</td>
<td>(later the quadrivium)</td>
</tr>
<tr>
<td>5. Music</td>
<td>(later the quadrivium)</td>
</tr>
<tr>
<td>6. Geometry</td>
<td>(later the quadrivium)</td>
</tr>
<tr>
<td>7. Astrology (or Astronomy)</td>
<td>(later the quadrivium)</td>
</tr>
<tr>
<td>8. Philosophy</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Muhammad al-Farabi (d. 950)</th>
<th>1. The linguistic sciences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2. Logic (Aristotle’s <em>Organon</em>)</td>
</tr>
<tr>
<td></td>
<td>3. Mathematics (arithmetic, geometry, optics, astronomy, music, statics, mechanics)</td>
</tr>
<tr>
<td></td>
<td>4. Physics (as structured by Aristotle)</td>
</tr>
<tr>
<td></td>
<td>5. Metaphysics</td>
</tr>
<tr>
<td></td>
<td>6. Politics</td>
</tr>
<tr>
<td></td>
<td>7. Jurisprudence</td>
</tr>
<tr>
<td></td>
<td>8. Theology</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ibn Sīnā (Abu Ali) (980-1037)</th>
<th>Rational sciences</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Speculative sciences (seeking truth)</td>
<td></td>
</tr>
<tr>
<td>1.1 Physics</td>
<td></td>
</tr>
<tr>
<td>1.1.1 Basic sciences (8 from Aristotle)</td>
<td></td>
</tr>
<tr>
<td>1.1.2 Derivative sciences</td>
<td></td>
</tr>
<tr>
<td>1.2 Mathematics</td>
<td></td>
</tr>
<tr>
<td>1.3 Music</td>
<td></td>
</tr>
<tr>
<td>2. Practical sciences (seeking well-being)</td>
<td></td>
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<tr>
<td>2.1 Personal morality</td>
<td></td>
</tr>
<tr>
<td>2.2 Domestic morality</td>
<td></td>
</tr>
<tr>
<td>2.3 Politics</td>
<td></td>
</tr>
<tr>
<td>2.4 Prophetology</td>
<td></td>
</tr>
</tbody>
</table>
| Robert Grosseteste  
(c.1175-1253) | Twenty departments of scientific knowledge known at the time, in the  
*Compendium Scientarium*  
1. The divisions of philosophy  
2. A compendium of natural philosophy  
3. Mathematics  
4. Metaphysics  
5. Grammar  
6. Rhetoric  
7. Logic  
8. Medicine  
9. Arithmetic  
10. Music  
11. Geometry  
12. Astronomy  
13. Optics  
14. Astrology  
15. Mechanics (astronomy)  
16. Mathematical sciences in general  
17. Politics  
18. Economics  
19. Ethics  
20. The unity and simplicity of knowledge |
|-----------------|---------------------------------------------------------------------------------------------------------------|
| Albertus Magnus  
(1193/1206-1280) | 1. Natural philosophy (physics)  
2. Metaphysics, with theology  
3. Mathematics |
|-----------------|---------------------------------------------------------------------------------------------------------------|
| Thomas Aquinas  
(Saint Thomas)  
(1227-1274) | 1. Natural philosophy  
2. Rational philosophy (The intellect mentally produces)  
3. Moral philosophy (The intellect generates through acts of will)  
4. Practical sciences (mechanical arts)  
(The intellect generates activities that produce things or change the external world) |
<table>
<thead>
<tr>
<th>Roger Bacon (1214-1292/94)</th>
<th>Parts of Opus Majus</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1. Four causes of human ignorance and error</td>
</tr>
<tr>
<td></td>
<td>2. Philosophy &amp; theology</td>
</tr>
<tr>
<td></td>
<td>3. Foreign languages</td>
</tr>
<tr>
<td></td>
<td>4. Mathematical sciences</td>
</tr>
<tr>
<td></td>
<td>4.1 Astronomy</td>
</tr>
<tr>
<td></td>
<td>4.2 Optics</td>
</tr>
<tr>
<td></td>
<td>4.3 Theology</td>
</tr>
<tr>
<td></td>
<td>4.4 Chronology</td>
</tr>
<tr>
<td></td>
<td>4.5 Astrology</td>
</tr>
<tr>
<td></td>
<td>4.6 Correction of the calendar - geography</td>
</tr>
<tr>
<td></td>
<td>5. Perspective or Optics</td>
</tr>
<tr>
<td></td>
<td>6. Experimental science</td>
</tr>
<tr>
<td></td>
<td>7. Moral philosophy</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Extant parts of Scriptum Principale</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1. Comparative grammar and logic (the trivium)</td>
</tr>
<tr>
<td></td>
<td>2. Mathematics (the quadrivium)</td>
</tr>
<tr>
<td></td>
<td>3. Natural science</td>
</tr>
<tr>
<td></td>
<td>3.1 General principles</td>
</tr>
<tr>
<td></td>
<td>3.2 Perspective or optics</td>
</tr>
<tr>
<td></td>
<td>3.3 Astronomy (including geography and astrology)</td>
</tr>
<tr>
<td></td>
<td>3.4 Barology (science of weights)</td>
</tr>
<tr>
<td></td>
<td>3.5 Speculative alchemy</td>
</tr>
<tr>
<td></td>
<td>3.6 Agriculture</td>
</tr>
<tr>
<td></td>
<td>3.7 Medicine</td>
</tr>
<tr>
<td></td>
<td>3.8 Experimental science</td>
</tr>
<tr>
<td></td>
<td>4. Metaphysics and morals</td>
</tr>
<tr>
<td></td>
<td>4.1 (probably like part 7 of the Opus Majus)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ramon Lull (or Raymond Lulle) (1234-1315)</th>
<th>Experimental science (in other works):</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Elementary tree (concerned with cosmogony)</td>
<td>1. Astronomy</td>
</tr>
<tr>
<td>2. Vegetal tree</td>
<td>2. Physics</td>
</tr>
<tr>
<td>3. Sensuous tree</td>
<td>3. Chemistry</td>
</tr>
<tr>
<td>4. Imaginal tree (concerned with mental impressions of elementary, vegetal and sensuous things)</td>
<td>4. Medicine</td>
</tr>
</tbody>
</table>
### Ibn Khaldūn (1332-1406)

| 1. Traditional sciences - ‘based on the authority of the given religious law’ |
| 1.1 Interpretation of the Qur’an |
| 1.2 Reading of the Qur’an |
| 1.3 Prophetic traditions |
| 1.4 Principles of jurisprudence (controversial questions & dialectics) |
| 1.5 Jurisprudence, including laws of inheritance |
| 1.6 Speculative theology, including degrees of faith, anthropomorphism, schools of theologians and philosophers |
| 1.7 Sufism (Mohammedan ascetic mysticism) |
| 1.8 Dream interpretation |

<p>| 2. Philosophical sciences - ‘natural to man [sic] and to which he is guided by his [sic] own ability to think’ |
| 2.1 Logic - divided into the 8 books of Aristotle’s <em>Organon:</em> |
| • categories |
| • hermeneutics |
| • analytics |
| • apodeictica |
| • topics |
| • sophistry |
| • rhetoric |
| • poetics |
| 2.2 Physics, mainly medicine and agriculture |
| 2.3 Metaphysics |
| • sorcery (magic) (possibly in physics?) |
| • talismans (possibly in physics?) |
| • letter magic (possibly in physics?) |
| • alchemy (possibly in physics?) |
| 2.4 Mathematical sciences |
| • geometrical sciences |
| • numerical sciences |
| • music |
| • astronomy |</p>
<table>
<thead>
<tr>
<th>Francis Bacon (1561-1626)</th>
<th>Three divisions of human learning ...</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. History (from memory)</td>
<td></td>
</tr>
<tr>
<td>1.1 Natural history</td>
<td></td>
</tr>
<tr>
<td>1.1.1 for narration</td>
<td></td>
</tr>
<tr>
<td>1.1.2 for induction 'the nursing mother of philosophy'</td>
<td></td>
</tr>
<tr>
<td>1.2 Civil history</td>
<td></td>
</tr>
<tr>
<td>2. Poësy (from imagination)</td>
<td></td>
</tr>
<tr>
<td>2.1 Narrative</td>
<td></td>
</tr>
<tr>
<td>2.2 Dramatic or Representational</td>
<td></td>
</tr>
<tr>
<td>2.3 Parabolical</td>
<td></td>
</tr>
<tr>
<td>3. Philosophy (from reason)</td>
<td></td>
</tr>
<tr>
<td>3.1 Universal science (<em>Philosophia Prima</em>)</td>
<td></td>
</tr>
<tr>
<td>3.1.1 Sacred theology; from revelation</td>
<td></td>
</tr>
<tr>
<td>3.1.2 Philosophy</td>
<td></td>
</tr>
<tr>
<td>3.1.2.1 Concerning the Deity (Natural Theology or Divine Philosophy); from contemplation</td>
<td></td>
</tr>
<tr>
<td>3.1.2.2 Concerning Nature (Natural Philosophy)</td>
<td></td>
</tr>
<tr>
<td>3.1.2.2.1 Inquisition of causes: Speculative</td>
<td></td>
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<tr>
<td>• physics</td>
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<tr>
<td>• principles of things</td>
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<td>• fabric of things</td>
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<td>• variety of things</td>
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<tr>
<td>- things concrete</td>
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<td>- things abstract</td>
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<tr>
<td>- configurations of matter</td>
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<td>- motions</td>
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<tr>
<td>- simple</td>
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<tr>
<td>- compound</td>
<td></td>
</tr>
<tr>
<td>• metaphysics</td>
<td></td>
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<tr>
<td>• final causes (from Aristotle)</td>
<td></td>
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<tr>
<td>• forms</td>
<td></td>
</tr>
<tr>
<td>- 'dense, rare, hot, cold, heavy, light, tangible, pneumatic, volatile, fixed, and the like'</td>
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</tr>
<tr>
<td>• mathematics</td>
<td></td>
</tr>
<tr>
<td>- pure</td>
<td></td>
</tr>
<tr>
<td>- mixed (explains some axioms and natural philosophy)</td>
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<tr>
<td>3.1.2.2.2 Production of effects: Operative</td>
<td></td>
</tr>
<tr>
<td>• mechanics</td>
<td></td>
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<tr>
<td>• magic</td>
<td></td>
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<tr>
<td>• alchemy</td>
<td></td>
</tr>
<tr>
<td>• astrology</td>
<td></td>
</tr>
<tr>
<td>3.1.2.3 Concerning Man [sic] (Moral Philosophy)</td>
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<tr>
<td>3.1.2.3.1 Man segregate</td>
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<tr>
<td>• the human body</td>
<td></td>
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<tr>
<td>• medicine</td>
<td></td>
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<td>• athletics</td>
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<tr>
<td>• the mind</td>
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<tr>
<td>• logic</td>
<td></td>
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<tr>
<td>• ethics</td>
<td></td>
</tr>
<tr>
<td>3.1.2.3.2 Man in society</td>
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<tr>
<td>Immanuel Kant (1724-1804)</td>
<td>Fundamental distinctions of knowledge, e.g.</td>
</tr>
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<tr>
<td></td>
<td>1. analytic and synthetic</td>
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<tr>
<td></td>
<td>2. phenomena and noumena</td>
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<td></td>
<td>3. intuition and perception</td>
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<td></td>
<td>4. theoretical and practical</td>
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<td></td>
<td>5. immanent and transcendent</td>
</tr>
<tr>
<td></td>
<td>6. empirical and transcendental</td>
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<thead>
<tr>
<th>Georg Hegel (1770-1831)</th>
<th>1. Logic</th>
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<tr>
<td></td>
<td>1.1 Being</td>
</tr>
<tr>
<td></td>
<td>1.2 Essence</td>
</tr>
<tr>
<td></td>
<td>1.3 Notion (what most philosophers would regard as logic)</td>
</tr>
<tr>
<td></td>
<td>1.3.1 the subjective forms of conception, judgement, syllogism</td>
</tr>
<tr>
<td></td>
<td>1.3.2 their realisation mechanically, chemically or teleologically</td>
</tr>
<tr>
<td></td>
<td>1.3.3 the ideas of life, science, and the interpenetration of thought and objectivity</td>
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<thead>
<tr>
<th></th>
<th>2. Nature</th>
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<tbody>
<tr>
<td></td>
<td>2.1 Mechanics</td>
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<tr>
<td></td>
<td>2.2 Physics</td>
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<tr>
<td></td>
<td>2.3 Organics (the three kingdoms of Nature)</td>
</tr>
<tr>
<td></td>
<td>2.3.1 Geology</td>
</tr>
<tr>
<td></td>
<td>2.3.2 Botany</td>
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<tr>
<td></td>
<td>2.3.3 Animal physiology</td>
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<thead>
<tr>
<th></th>
<th>3. Mind</th>
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<tbody>
<tr>
<td></td>
<td>3.1 The Subjective mind</td>
</tr>
<tr>
<td></td>
<td>3.1.1 Anthropology</td>
</tr>
<tr>
<td></td>
<td>3.1.2 Phenomenology (consciousness, self-consciousness, reason)</td>
</tr>
<tr>
<td></td>
<td>3.1.3 Psychology (in the narrower sense)</td>
</tr>
<tr>
<td></td>
<td>3.2 The Objective mind</td>
</tr>
<tr>
<td></td>
<td>3.2.1 Philosophy of Law</td>
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<tr>
<td></td>
<td>3.2.2 Moral Philosophy</td>
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<tr>
<td></td>
<td>3.2.3 Political Philosophy</td>
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<tr>
<td></td>
<td>3.3 The Absolute mind</td>
</tr>
<tr>
<td></td>
<td>3.3.1 Philosophy of Art</td>
</tr>
<tr>
<td></td>
<td>3.3.2 Philosophy of Religion</td>
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<tr>
<td></td>
<td>3.3.3 History of Philosophy (Philosophical Theory).</td>
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<table>
<thead>
<tr>
<th>André Ampère (1775-1836)</th>
<th>1. Cosmological sciences</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>1.1 Mathematical sciences</td>
</tr>
<tr>
<td></td>
<td>1.1.1 arithmology</td>
</tr>
<tr>
<td></td>
<td>1.1.2 geometry</td>
</tr>
<tr>
<td></td>
<td>1.1.3 mechanics</td>
</tr>
<tr>
<td></td>
<td>1.1.4 uranology</td>
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<tr>
<td></td>
<td>1.2 Physical sciences</td>
</tr>
<tr>
<td></td>
<td>1.2.1 physics</td>
</tr>
<tr>
<td></td>
<td>1.2.2 chemistry</td>
</tr>
<tr>
<td></td>
<td>1.2.3 technology</td>
</tr>
<tr>
<td></td>
<td>1.2.4 geology</td>
</tr>
<tr>
<td></td>
<td>1.2.5 mineralogy</td>
</tr>
<tr>
<td></td>
<td>1.2.6 oryctotechnics (technology of extractive industries)</td>
</tr>
</tbody>
</table>

<p>|                        | 2. Noological sciences |</p>
<table>
<thead>
<tr>
<th>August Comte</th>
<th>1. Practical Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1798-1857)</td>
<td>2. Theoretical Knowledge</td>
</tr>
<tr>
<td></td>
<td>2.1 Mathematics</td>
</tr>
<tr>
<td></td>
<td>2.2 Astronomy</td>
</tr>
<tr>
<td></td>
<td>2.3 Physics</td>
</tr>
<tr>
<td></td>
<td>2.4 Chemistry</td>
</tr>
<tr>
<td></td>
<td>2.5 Physiology (Biology)</td>
</tr>
<tr>
<td></td>
<td>2.6 Social Science ('Social Physics')</td>
</tr>
</tbody>
</table>
| Karl Pearson (1857-1936) | 1. Abstract sciences  
1.1 kinematics  
1.2 theory of strain  
1.3 theory of observation and description (a part of logic)  
1.4 trigonometry  
1.5 descriptive geometry  
1.6 theory of functions  
1.7 calculus of fluxions and calculus of sums (differential and integral calculus)  
1.8 arithmetic  
1.9 statistics  
1.10 logic  
1.11 orthology (a part of grammar)  
1.12 methodology  
2. Concrete sciences  
2.1 Sciences dealing with inorganic phenomena  
2.1.1 Exact or precise sciences: phenomena reduced to ideal motions  
• theories of light, heat, electricity, dispersion, absorption, transmission, conduction and radiation  
• theoretical chemistry, spectrum analysis, solar and sidereal physics  
• theories of elasticity, plasticity, cohesion, sound, crystallography, hydromechanics, aeromechanics, the tides, kinetic theory of gases  
• mechanics, planetary theory, lunar theory  
2.1.2 Synoptic or descriptive physical sciences: not yet reduced to ideal motions  
• nebular theories  
• evolution of planetary systems  
• geology  
• physical geography  
• meteorology  
• mineralogy  
• chemistry  
2.2 Sciences dealing with organic phenomena  
2.2.1 Sciences emphasising space or localisation  
• Chorology (geographical distribution of living forms)  
• Ecology (habits in relation to situation and climate)  
• Natural history  
2.2.2 Sciences emphasising time, change or growth  
2.2.2.1 Biology  
• botany  
• zoology, includes all sciences of man, except theories of sex and heredity, and all of sociology  
* functions and actions - psychology, physiology  
* growth and reproduction - embryology, theories of sex and heredity  
* form and structure - morphology, histology, anatomy  
2.2.2.2 History  
• evolution of species, theories of natural and sexual selection  
• anthropology, histories of language, science, philosophy, art, etc., and social institutions such as archaeology, folklore, histories of customs, marriage, ownership, religions, states, laws, etc. |
### Appendix B.4: Structure

**Otto Neurath (1882-1945) and Rudolf Carnap (1891-1970)**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>1.</td>
<td>Formal science: 'analytical statements established by logic and mathematics'</td>
</tr>
<tr>
<td>2.</td>
<td>Empirical science: 'synthetic statements established in the different fields of factual knowledge'</td>
</tr>
<tr>
<td>2.1</td>
<td>Physics (nonbiological field of science) (does not presuppose biology)</td>
</tr>
<tr>
<td>2.1.1</td>
<td>Both systematic and historical investigations of the field</td>
</tr>
<tr>
<td></td>
<td>chemistry</td>
</tr>
<tr>
<td></td>
<td>mineralogy</td>
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<tr>
<td></td>
<td>astronomy</td>
</tr>
<tr>
<td></td>
<td>geology</td>
</tr>
<tr>
<td></td>
<td>meteorology, etc.</td>
</tr>
<tr>
<td>2.2</td>
<td>Biology (presupposes physics)</td>
</tr>
<tr>
<td>2.2.1</td>
<td>Biology in the narrower sense</td>
</tr>
<tr>
<td></td>
<td>general biology</td>
</tr>
<tr>
<td></td>
<td>botany</td>
</tr>
<tr>
<td></td>
<td>the greater part of zoology</td>
</tr>
<tr>
<td>2.2.2</td>
<td>No name in general use</td>
</tr>
<tr>
<td></td>
<td>Dealing with individual organisms (perhaps psychology)</td>
</tr>
<tr>
<td></td>
<td>* psychology, parts of physiology and the humanities</td>
</tr>
<tr>
<td></td>
<td>Dealing with groups of organisms (perhaps social science)</td>
</tr>
<tr>
<td></td>
<td>* social science, the greater part of humanities and history</td>
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</table>

**Britannica 3, Mortimer Adler (1902-) and the Propaedia**

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>1.</td>
<td>Matter and energy</td>
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<tr>
<td>2.</td>
<td>The Earth</td>
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<tr>
<td>3.</td>
<td>Life on Earth</td>
</tr>
<tr>
<td>4.</td>
<td>Human life</td>
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<tr>
<td>5.</td>
<td>Human society</td>
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<td>6.</td>
<td>Art</td>
</tr>
<tr>
<td>7.</td>
<td>Technology</td>
</tr>
<tr>
<td>8.</td>
<td>Religion</td>
</tr>
<tr>
<td>9.</td>
<td>The history of mankind</td>
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<tr>
<td>10.</td>
<td>The branches of knowledge</td>
</tr>
<tr>
<td>10.1</td>
<td>Logic</td>
</tr>
<tr>
<td>10.2</td>
<td>Mathematics</td>
</tr>
<tr>
<td>10.3</td>
<td>Science</td>
</tr>
<tr>
<td></td>
<td>history and philosophy of science</td>
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<tr>
<td></td>
<td>the physical sciences</td>
</tr>
<tr>
<td></td>
<td>the earth sciences</td>
</tr>
<tr>
<td></td>
<td>the biological sciences</td>
</tr>
<tr>
<td></td>
<td>medicine and affiliated disciplines</td>
</tr>
<tr>
<td></td>
<td>the social sciences and psychology</td>
</tr>
<tr>
<td></td>
<td>the technological sciences</td>
</tr>
<tr>
<td>10.4</td>
<td>History and the humanities</td>
</tr>
<tr>
<td>10.5</td>
<td>Philosophy</td>
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**Dissertation Abstracts International (March 1990)**

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<table>
<thead>
<tr>
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<tbody>
<tr>
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<td>Biological sciences</td>
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<td>Agriculture</td>
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<td>General</td>
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<tr>
<td></td>
<td>Agronomy</td>
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<td></td>
<td>Animal culture and nutrition</td>
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<td></td>
<td>Animal pathology</td>
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<td></td>
<td>Food science and technology</td>
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<td>Forestry and wildlife</td>
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<td>Plant culture</td>
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<td>Plant pathology</td>
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<td>Plant physiology</td>
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<td></td>
<td>Range management</td>
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<td>Wood technology</td>
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<td>Anatomy</td>
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<td>Biological oceanography</td>
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<td>1.4</td>
<td>Biology</td>
</tr>
<tr>
<td>1.5</td>
<td>Biophysics</td>
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</table>
4. Physical sciences
   4.1 Pure sciences
      4.1.1 Chemistry
         • General
         • Agricultural
         • Analytical
         • Biochemistry
         • Inorganic
         • Nuclear
         • Organic
         • Pharmaceutical
         • Physical
         • Polymer
         • Radiation
      4.1.2 Mathematics
      4.1.3 Physics
         • General
         • Acoustics
         • Astronomy and astrophysics
         • Atmospheric science
         • Atomic
         • Electronics and electricity
         • Elementary particles and high energy
         • Fluid and plasma
         • Molecular
         • Nuclear
         • Optics
         • Radiation
         • Solid state
      4.1.4 Statistics
   4.2 Applied sciences
      4.2.1 Applied mechanics
      4.2.2 Computer science
      4.2.3 Engineering
         • General
         • Aerospace
         • Agricultural
         • Automotive
         • Biomedical
         • Chemical
         • Civil
         • Electronics and electrical
         • Heat and thermodynamics
         • Hydraulic
         • Industrial
         • Marine
         • Materials science
         • Mechanical
         • Metallurgy
         • Mining
         • Nuclear
         • Petroleum
         • Sanitary and municipal
         • System science
      4.2.4 Geotechnology
      4.2.5 Operations research
      4.2.6 Textile technology
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<td>- Clinical</td>
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<td>- Personality</td>
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<td>- Physiological</td>
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<td>- Psychobiology</td>
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<td>- Psychometrics</td>
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<td>- Social</td>
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Appendix B.5

Argument from the metascientific literature emphasising the dimension activity

Debates in the metascientific literature address many aspects of scientific activity, again supporting a broad interpretation of scientific activity. It is clear that the literature draws upon a broader notion of activity than many individual thinkers have proposed. This breadth is interpreted both as a wider range of activities than many individual accounts recognise, and as different interpretations of the same activities. The variations, implications and subtleties of the views in several of these debates are outlined here in Appendix B.5, to indicate the scope of the ways in which science is characterised partly by activity and some issues which are used in relation to this characteristic:

B.5.1 Activity as observable and non-observable;
B.5.2 Activity as method and methodology;
B.5.3 The characterisation of a Western European scientific tradition by activity;
B.5.4 The problem of induction;
B.5.5 The characterisation of key metascientific viewpoints by activity;
B.5.6 The notion of a uniform method of science;
B.5.7 Interpretations of some characteristic scientific activities: experiment, observation, explanation and prediction;
B.5.8 Mathematical activities in science;
B.5.9 Debate over discovery and verification;
B.5.10 Activity as more than method and methodology: internalist and externalist perspectives on scientific activity.

5.1 Activity as observable and non-observable

Science is characterised most obviously by - and indeed is manifest in - observable or motor activity. Some of the activities identified in the summary statements are observable behaviours or form part of observable behaviours, such as delicate manipulations. Clearly, these activities are a characteristic by which science is recognised by the scientific community and general community alike. The image of a person (very often a male and wearing a laboratory coat) manipulating intricate chemical glassware, observing through a microscope, spectroscope or telescope, or taking a reading from a thermometer, would be interpreted widely as someone ‘doing’ science.
However, scientific activity is not always observable. Many of the activities identified in the summary statements are non-observable, or mental, such as comparing, controlling variables, evaluating, experimenting, explaining, predicting, etc.:

Science, as practiced, involves an ongoing process of observation, experiment, recourse to prior theory, reliance on various metaphysical principles, and so on, exploited via reason and argument to suggest hypotheses, evaluate their promise for further development, debate their adequacy, develop them further, accept or reject them as true or false, the point of the enterprise being to obtain systematic knowledge that provides understanding of the world we live in. Whether or not its use of it is very good, far more of science is concerned with reasoning, argument, and marshalling evidence than with manipulating nature in the laboratory. In short, a central and characteristic activity of science is the use of reason in the suggestion and development of hypotheses and theories and in evaluating the knowledge claims made by those who advance such hypotheses and theories. (Suppe 1979, p. 650)

Considerable significance is attached in the metascientific literature to these activities, as indicated by the volume and variety of work devoted to their explication and theoretical interpretations. This significance does not arise from a debate about whether or not the activity is observable or mental in itself, but from its contribution to achieving a particular purpose or end. Here is a second account which makes a similar distinction to Suppe, above, but with different terminology and slightly different argument:

All scientific methods may be divided basically into two major categories: (1) technical, and (2) logical. The technical aspects of science differentiate the various sciences from each other - astronomy from chemistry, and chemistry from social science. For the major difference between the particular sciences lies in the type of measuring instruments or measuring methods used to gather data, or the type of observation employed, or the specific natural phenomena investigated. Competence in dealing with a cloud chamber or a stethoscope, or with particulate matter or a sick patient alone distinguishes physicist from physician. Both of them can be serious scientists or both of them can be dilettantes. In this paper we cannot consider the logical approaches involved in scientific methods, since they are all basically the same and fundamental to all scientific methods. Stated simply, the logical components of scientific methods involve reasoning about the facts in order to understand them better and to devise an orderly array between apparently disconnected facts. One thus attempts to place as many different kinds of specific facts into more general terms or laws. (Hodes 1974, pp. 355-6)

Our attention is drawn, therefore, not to the mental or non-observable state of certain activities, but to a distinction between what Hodes calls technical and logical methods. They are interpreted here to be, respectively, methods involving the collection of data and the reasoning towards some understanding of that data. There is far more discussion on logical than technical processes in the metascientific literature, from which we can infer that greater significance is attached to debates about how experimental inquiries and explanations should be constructed and justified, than to physical manipulations and operations. Also, conceptions of scientific activity have undergone considerable changes in their development, are still developing and do not yet enjoy consensus. Analysis,
Appendix B.5: Activity 784

below, of examples from the literature indicates some strengths and difficulties associated with Hodes' position in characterising science.

There is some commonsense support for Hodes' distinction. It is true that the text units indicating process or activity in Tables A.4 and A.9 do include some commonly taken to indicate mental or logical activities (such as hypothesising, deductions and predicting), and some commonly taken to indicate technical or observable activities (such as experimenting and delicate manipulations). This distinction can be supported also with examples from histories of science. For example, characterisations of the Scientific Revolution commonly name the writings of Francis Bacon and Rene Descartes as exemplifying the opposing views of scientific methods that arose then, respectively inductive/empirical and deductive/rationalistic. These may be interpreted to approximate logical methods as proposed by Hodes. More clearly, Galileo's astronomical observations pioneering the use of the telescope, and Spallanzani's considerable corpus of experimental biology are cited as exemplifying the developments in technical methods seen as characterising the science of that time. We recognise the writings of Bacon and the observations of Galileo as being scientific, or as characterising science at a point in its historical development, at least partly in terms of logical and technical methods.

A specific example in which technical and logical methods can be identified in the following two passages concerning the work of Robert Boyle (1627-91):

The air-pump of Guericke was considerably improved (1658-9) by Robert Hooke (1635-1703) working at Oxford for his employer Robert Boyle. Hooke was one of the most skilful and ingenious of physical experimenters, Boyle one of the ablest and most suggestive of scientific investigators. A large part of the foundations of the modern sciences of chemistry and physics in their various departments was laid down by these two men.

By means of the air-pump Boyle and Hooke examined the elasticity, compressibility, and weight of the air (1660) ...

Boyle's name is familiarly recalled in 'Boyle's law' which states that the volume of a gas varies inversely as the pressure upon it, provided the temperature be constant. Boyle took a U-shaped tube with a shorter closed and a longer open limb. By pouring mercury into it he cut off air in the short limb and, by shaking, the mercury was brought to the same level in both limbs. The air in the short limb was now under atmospheric pressure. Adding mercury to the long limb he could increase the pressure continuously, thereby reducing the bulk of contained air. Thus when the barometric pressure stood at 30 inches above the level in the short limb, the pressure on the imprisoned air was doubled. The bulk of that air was then found to be reduced to one half. Under three times the atmospheric pressure it was reduced to a third, and so on. Moreover, he could reverse the process. (Singer 1959, pp. 271-2)

Boyle's most important early experiments were based on the use of the air pump. Having repeated all the experiments of Guericke as described by Kaspar Schott (1608-66) in his Mechanica Hydraulica-Pneumatica (1657), he added certain new ones of his own such as the fact that warm water boiled under reduced pressure. These experiments were gathered together in the New Experiments Physico-Mechanickal (1660). In an appendix to a new edition of this latter work, he published the famous law which goes by his name, though this was, in fact, discovered by one of his assistants, R. Towneley. In his last
work, the *General History of the Air* (published posthumously, 1692), he returned to the same subject again, giving a very clear qualitative expression of the notion of heat as due to an increase in the motion of the ultimate particles of a gas.

... What was original in Boyle was his enormous ingenuity in constructing experiments in support of the atomistic hypothesis. Here his influence was profound. Through his writings a belief in atomism in Europe was greatly strengthened. He was also very influential for the example he provided of the prosecution of the experimental method in science in the manner of Galileo and his Florentine successors. (Herivel 1969, pp. 74-5)

The question to be asked is, What is being done or is happening here?, or more directly, What activity is indicated here? Both excerpts mention observable, or technical, activity in connection with an air pump and, in Singer’s account, other artefacts also. However, the use of particular artefacts in the activity appears to be deemed significant not so much for their own sake, but for the activities they enable. Artefacts are involved in carrying out many observable activities, methods or processes, as the examples above show. Artefacts may be involved also in carrying out non-observable activities: the very same microscope or test tube may be the means by which the scientist compares phenomena and subsequently makes conjectures, controls variables or replicates results.

Since scientific artefacts are associated with both observable and non-observable activity, appeal to artefacts is not central to a distinction between them or to an argument for their significance. Many references to scientific activity in the literature make little or no mention of the artefacts involved. Science is not an artefact: it is not a microscope, bunsen burner, test tube or spectroscope. Artefacts do, however, comprise part of the contexts in which and through which particular activities are carried out. In both passages the significance of Boyle’s activity lies only partly with his careful manipulation of equipment and measurement of the pressure and volume of gases. Greater significance is attached to his repetition (specifically of Guericke’s work and implicitly of his own work), of his comparison of readings, and of his controlling variables (the temperature, to avoid confusing his results, and the pressure, with which he compared his measurements of volume). By implication the data was interpreted and the relationship between the pressure and volume was tested after some sort of hypothesising or speculating, which Herivel points out was actually the work of Towneley. These activities are all mental or logical. Ingenuity is mentioned by Herivel, and is integral to his characterisation, but is a capacity or disposition rather than an activity1.

Closer examination of the passage from Herivel, above, highlights further points worthy of comment. The second sentence refers to Boyle adding certain new [experiments] of his own, yet provides as an example, such as the fact that warm water boiled under reduced pressure. This is not an experiment but a generalisation of experimental results, which emphasises the point that observable/technical and

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1 This is discussed in the companion chapter on belief system and Appendix B.2.
reasoning/logical activities are not easily distinguished, a point taken up shortly. Further on we read that Towneley discovered the law that we know as Boyle's; quite aside from metascientific contention about the label laws, discussed in the companion chapter on structure, the question of whether scientific relationships and 'facts' are discovered or invented or constructed is also a topic of debate, and is discussed later in this chapter. Less contentious but nonetheless worthy of mention is the close of the first paragraph, giving a very clear qualitative expression ..., which the present thesis interprets as explaining the concept heat in terms of the motion of the particles of gas. The point here is that clearer identification of the activities mentioned clarifies the meaning of the larger unit of text, and hence the characterisation of science.

The limitations of distinguishing technical and logical activities

The accounts of Boyle's work, above, illustrate an important and more general point of characterisation, that technical and logical activities are difficult to distinguish in practice, even though they are conceptually distinct. First, we have noted that some terms are not clearly distinguished as logical or technical, such as method, classifying, procedures, research and solution of in Tables A.4 and A.9, examined in Singer, above, and constructing experiments in Herivel, above. Searching for such a clear distinction has the potential to lead prolonged linguistic analysis of peripheral use to the present paper. In any event, it is clear from the examples above that the authors used the terms in a more comprehensive sense that would be misrepresented if described is either technical or logical.

Second is the difficulty of separating technical from logical in practice. Technical activity that is consciously and purposefully performed must entail thinking processes, and where it is performed without logical or reasoning activities its status as scientific activity is questioned. The observable manifestations of experimenting, for example, are merely mechanical behaviours without considering an associated logic, context, purpose and rationale. The young child manipulating laboratory glassware is not doing science. Often the technical processes that partly characterise science have been done by research assistants for scientists, but the minutiae of laboratory activity is rarely mentioned in the metascientific literature. (The recent metascientific interest in transcribing laboratory activities is a significant exception and is addressed later in this chapter). On the other hand, the work of Galileo and Spallanzani, for example, is recorded in the history books because their technical methods were fruitfully combined with logical methods, by which they controlled variables, made predictions and deductions, and interpreted data in terms of theories. Conversely, logical activities cannot be considered meaningfully without the observable activities they entail. For example, it makes no sense to speak of hypothesising or predicting without also considering their articulation, in both the sense of clarifying them as part of scientific communication and of linking them meaningfully to
other activities. This is clear in many historical examples, as in this case of the rapid development of chemical analysis without commensurate development of classification (and, in turn, interpretation):

The investigation of chemical processes in the seventeenth century had yielded, by the dawn of the eighteenth, a vast accumulation of facts for which no satisfactory system of classification had been suggested. (Singer 1959, p. 333)

In these ways, what may be inferred as discrete activities because they are labelled by single words, are clearly parts of larger ‘webs’ of activities for which the label-boundaries are unclear. However interpreted, the important point is that these activities are common means by which science is characterised.

In summary, while the popular image of scientists is partly characterised by observable activities, many activities - in many ways the more significant ones - are not observable. These activities are labelled variously, such as logical or reasoning for non-observable activities, which indicates a difference in interpretive focus more than fundamental difference. Whether or not particular reasoning/logical activities are conceptually distinct from mechanical/technical activities, they are less distinct in practice. More importantly here, they work together, and their significance is made clearer when interpreted together with the other dimensions of science.

5.2 Activity as method and methodology

Greater explanatory power is promised by attention to a distinction between method, of whatever type, and methodology. Method is taken to be ‘a mode or procedure, especially an orderly or systematic mode’. Methodology is taken to be ‘the science of method, especially a branch of logic dealing with the logical principles underlying the organisation of the various special sciences, and the conduct of scientific inquiry’ (The Macquarie Dictionary), or ‘the procedures and techniques governing inquiry, or the study of such procedures and techniques’ (Boyd, Gasper & Trout 1991, p. 778). Thus methods, like collecting data or controlling variables, are interpreted in terms of theoretical constructs or methodologies, like proving (a now discredited methodology), verifying or falsifying.

The activities we have been discussing have metascientific interest because of their role in developing a claim to scientific knowledge. For example, Herivel’s account of Boyle’s work, above, placed great significance on constructing experiments in support of the atomistic hypothesis. Accordingly, our attention is drawn not simply to particular methods, but to their use in making some argument, demonstration or proof and a rationale for this deployment. This represents an ‘interaction of evidence, argument, and hypotheses’, which we understand by methodology:
[Methodology is] the theory of method, of the rules and evaluations that should govern (or do not govern) the interaction of evidence, argument, and hypotheses, particularly in the empirical realm; sometimes, the system of rules itself. Methodology is not the same as epistemology; epistemology says what we can know, methodology elucidates ways and means. The epistemology of fallibilist justificationism - knowledge rests on positive, though inconclusive, evidence - has inspired methodologies endorsing the quest for well confirmed (sometimes, highly probable) hypotheses; all methodologies appealing to some principle of induction appear here, as well as most contemporary schools of statistics. The fallibilist but non-justificationist epistemology of conjectures and refutations is pursued in falsificationism, which dictates that evidence operate only negatively. Although methodologies differ widely, the methods recommended are often similar. All, except the methodology of scientific research programs, agree that adverse evidence cannot be disregarded; few contest that ad hoc hypotheses must be used sparingly, if at all; falsificationism and Bayesian personalism alike esteem severity in tests. The task of a methodology, however, includes making sense of the rules it advocates, and showing how they contribute to the rationality of science. (Miller 1983, p. 267)

This conception of methodology is interpreted here as the dynamic and reciprocal influence of interactions between three characteristics: evidence (data serving as criteria, which arises from investigative or other activities), argument (a process of reasoning or rhetoric) and hypotheses (statements of a certain form, arising from processes of explanation and conjecture). Methodologies are different in different accounts of epistemology.

There is considerable metascientific interest in methodology and method. The mastery of particular methods seems often to be a technical matter, of refining technical skills; it is the understanding, contribution and deployment of methods that is subject to the broader debates. Interest in method and methodology arises not just because of their importance in understanding science, but because of lack of agreement about the nature and role of particular methods in the face of scientific successes. There are different interpretations within and between different metascientific traditions, such as HPS and STS, each drawing upon historical examples. See the discussion of Table B.5.1, below.

Mismatches between methods and theories of why they are significant (methodologies)

Another point of metascientific interest in the distinction between method and methodology is when the two do not match. For example, with the flurry of experimental successes in the Scientific Revolution, experimental techniques blossomed without an agreed account of why they were successful. That is, the emerging methodologies did not match the development and application of methods, a gap which fuels metascientific interest down to the present. Scientific activity developed at such a rate and in so many locations that at times large amounts of knowledge accumulated without adequate theoretical frameworks for either the knowledge or the status of the knowledge (that is, epistemological and methodological theories). The discrepancies between methods in theory and methods in practice has not been resolved: we have noted above that in the latter half of the twentieth century there is no agreed, single, metascientific view, as the
RV was for much of the first half. Section 5.4, below, outlines a long-recognised problem in metascience, that science activity is commonly characterised by induction even though induction is logically flawed. The attempt to understand experimental activity, and scientific activity more generally, remains a current metascientific issue. Indeed, it is part of the rationale of the present thesis.

There has been interest also in the differences between the written accounts of science activity and the actual activities of scientists. For example, Francis Bacon is characterised often as the paradigmatic empiricist: his account of inductive activity was seminal and was written prescriptively. However, this is partly misleading in two respects. First, Bacon was a metascientist, not a scientist, and the scientific processes advocated in his writings were popularised by others, such as Hooke, who nonetheless did not follow Bacon strictly in their own successful experimental work. Secondly, there is also a deductive or rationalist element in Bacon’s writings that often is not acknowledged in the literature. Conversely, Descartes’ rationalistic writings do not give an account of his successful empirical activities. Newton and Galileo made useful contributions to the development of both technical and logical scientific processes, yet examples are recorded where their writings differed from their practice. Although Newton rejected the hypothesising characteristic of Descartes’ approach, he nonetheless made some assumptions, such as the existence of absolute space and time, and of the uniformity of Nature. Also, ‘interest in the concrete details of scientific progress soon drew attention away from abstract issues of methodology’ (Cohen 1983, p. 203). There are many current examples also, such as the persistent use of induction by scientists, in which there is not yet an agreed metascientific account of the (fruitful) actual activities of scientists. Some examples are discussed in section 5.7 below, such as interpretations of experiment, including the emerging field of laboratory studies in STS, and interpretations of observations, explanations and predictions. These are all examples of interest in characterising science by activity, where the analysis of activity utilises the concepts of method and methodology. Issues arising from this interest form the basis of the remainder of this section.

5.3 The characterisation of a history of a Western European scientific tradition by activity

Histories of the western European scientific tradition routinely characterise science by activity. This tradition was addressed generally in Appendix B.1 on context, but the present section will show how the literature characterises an historical tradition partly in terms of historical developments of activity. The scope of the present section will be confined to just a few parameters that indicate the role of activity in characterising an historical tradition.
5.3a. Historical confusion of terms

The historical development of terms concerning scientific activity partly characterises the historical development of science and thinking about science. For example, the historical uses of the terms *induction* and *deduction*, and related terms, is an example of the, often confused, development of terms and the activities they represent. They indicate a process in which successive, and sometimes, contemporaneous, thinkers proposed, debated and refined notions of these activities. Some of the confusion arose through contradictory usage, as with Newton and Hooke for example, who used the terms *analysis* and *synthesis* in exactly opposite ways (Oldroyd 1989, p. 81). Other confusion arose from similarities and differences in the use of different pairs of terms:

But, in the geometric example [of Pappus], it should be noted that the procedures in the analytic and synthetic phases of the reasoning process were both deductive; neither was inductive. So we cannot ... directly identify induction with analysis, and deduction with synthesis. Yet something like this identification did occur in subsequent authors. There arose, therefore, a mighty confusion in the terminology of metascience, which persisted well into the nineteenth century. There were, in fact, no less than three traditions that became conflated one with another: the geometrical analysis and synthesis that we have just considered; the methodological tradition of analysis and synthesis (induction and deduction, or resolution and composition); and also the rhetorical procedures of thinking up ideas and then presenting them to one’s auditors in a clear and logically coherent manner. For this last, the terms ‘invention’ and ‘judgement’ were commonly employed. Discussion on ‘method’ commonly treated rhetorical, scientific/empirical, and mathematical procedures together, without clearly differentiating one from another ... Another possible source of confusion lay in the titles of Aristotle’s two main logical works. Roughly speaking, one may associate the *Prior Analytics* with deductive logic and the *Posterior Analytics* with induction and the discovery of definitions, essences, first principles, and so on. (Oldroyd 1989, pp. 27-8)

This passage itself is an historical overview of considerable scope in which science is partly characterised by activity, although the particular interest is in induction and deduction as logical activities.

5.3b. Characterisations of a history of western European scientific tradition by observable, technical activities

Although we have noted that technical and logical activities are difficult to separate in practice, the western European scientific tradition is characterised partly by the observable, technical activities. They attract comparatively less metascientific interest than reasoning/logical activities, probably due in part because their visibility makes them less in need of explication, and in part because they are less significant interpretatively. Nevertheless, Molland (1990) judges the work of Aristotle to be more recognisably scientific than that of Plato because for Aristotle, unlike Plato, the investigation of Nature necessarily rested on observations or sense data, that is, the collection of empirical information. The judgement that there was relatively little scientific progress in the Middle Ages is made partly in terms of technical processes: instead of pursuing the *empirical*
activities advocated by Aristotle, the scholastics emphasised study and interpretation of Biblical Scriptures and Aristotelian texts and commentaries. Some empirical work in the Aristotelian tradition continued during that time, however, in Islamic countries. The argument that there was some scientific work done in Europe, leading up to the Scientific Revolution, is made partly on the basis of technical processes. The alchemists, for example, carried out a good deal of activity that is commonly identified as technical scientific activity from a twentieth century perspective. The judgement that their work had mediaeval characteristics is also made partly on the basis of logical processes (that is, mental activity) and partly on purposes and belief system (see Needham, summary statement 72; Bronowski 1978). This is addressed in Appendices B.2, B.3 and B.5.

The period roughly 1450-1750 is characterised popularly as the Scientific Revolution in part due to the flurry of experimental work and advances in experimental techniques and apparatus. There were many developments, in many (frequently new) areas. Contributions were made by many people, who often experimented in more than one field. Scientific activity in the period 1600-1850 included significant developments in at least the following areas, using the categories of that time rather than those used today: acoustics and music theory; astronomy; plant and animal anatomy, morphology and palaeontology; cell theory; chemistry; crystallography and geology; explanation in terms of atomic and molecular theory; experimental logic; the distribution of living things; electricity; elements; embryology; energy; gases; geology; geophysics; heat; hydrostatics; light; magnetism; measurement of the earth and cartography; mechanics; microscopy; optics; physiology; reproduction; taxonomy; and the use of mathematics in science, notably the development of the calculus. Other developments that facilitated new experimental activity included the developments of the air pump, microscope and telescope; the first state observatory of modern times; the first university laboratory; and developments in the measurement of temperature and time. Some of the activities outlined above represent significant developments of existing practice, such as new techniques, and an unprecedented increase in quantity within existing fields, such as astronomy, mechanics, chemistry, taxonomy and physiology. Others represent developments in new areas of study, such as microscopy and cell theory. In many of these fields, the development of more accurate scientific instruments enabled the more precise measurements that helped the mathematisation of physics from about 1770 (Feldman 1983, p. 251).

Similarly, developments in twentieth century science have been characterised partly in terms of the rapid developments in scientific technologies and associated techniques:

The term 'technification of the sciences' designates a process whereby techniques - frequently, though not always involving technology - become preponderant over earlier, more traditional methods of the practice of research. Thus, as a result of technification, theory construction has to some extent been rendered redundant through the systematic application of techniques and
technical procedures to the given materials of research; these might be collections of data to be analysed, or problems to be solved, or given practical results to be produced, or proof constructions to be formed, or whatever else might be the set task to be achieved by technical elaboration. Thus, as the physicist Ziman (1976) puts it, 'research itself - the tussle with a problem of natural philosophy - has given way to professional expertise in a variety of techniques.' Of course, techniques have also played a partial role in most sciences in the past, and almost no science has been without technical features. Under the general heading of tools, Ravetz establishes techniques as an inherent feature of the methods of science. But, as I shall show, there is an enormous disparity between the tools or techniques utilised in the traditional sciences during the Classical era, the days of string-and-sealing-wax devices, and those now employed. Most obviously, the nature and role of technological tools in contemporary science are very different from those of the craft tools that were available to many sciences even late in the era of Classical science during the early years of this century. The computer, for example, is no longer on the same level as many of the craft tools. The ready availability of computers brings about far-reaching changes in the practice of science, for utilising these tools in a science restructures the whole process of research and alters the very meaning of data and knowledge. Computerised knowledge is technified knowledge. (Redner 1987, pp. 64-5)

That is, Redner asserts that science is now significantly different from science in the Classical era, and attributes this at least in part to fundamental changes in scientific activity. In claiming that the use of computers has altered fundamentally both research and the 'very meaning of data and knowledge', Redner points to sciences where 'the instrument itself is being explored and theories devised and objects found to satisfy the results of that exploration' (Redner 1987, p. 65). More is said on the effect of changes in instruments in Appendix B.1, which includes the physical contexts of science. For the present thesis, Redner's analysis illustrates the use of technical activity in characterising recent changes in science in an historical context.

In summary, it is too simplistic to characterise the history of science as the history of technical scientific activities, because this thesis argues for a more sophisticated characterisation. However, it is clearly the case that even in general scientific histories science is partly characterised by technical or mechanical activity.

5.3c. Characterisations of a western European scientific tradition by reasoning activities and methodologies

A western European scientific tradition is more commonly characterised by the development of reasoning activities and methodologies, rather than by technical activities.

Historical themes based on activity

There have been a number of methodologies proposed, from the Greek philosopher-scientists down to the present, that interpret scientific activity in terms of variants of induction and deduction, and often in combination (see, for example, Singer 1959; Losee 1980; Bhaskar 1983b; Cohen 1983; Oldroyd 1989; Tarnas 1991). These activities are used to characterise the historical developments of science, mostly as they
Appendix B.5: Activity

contributed to current conceptions of science. In a general or lay sense they also remain part of public perceptions of science, and of thinking in school science and science education. They are significant, therefore, because of their historical role in characterising science as antecedent to current ideas, and because they remain part of the current lexicon for some of the notional readership of theses such as the present one.

*Induction* and *deduction* are interpreted initially, here, in their general senses, although we will examine some detailed issues later:

*Induction:*
a process of discovering explanations for a set of particular facts, by estimating the weight of observational evidence in favour of a proposition which (usually) asserts something about that entire class of facts.

*Deduction:*
the process of drawing a conclusion from something known or assumed. (both, *The Macquarie Dictionary*)

Together they can be interpreted historically as a set of activities involving observing particular phenomena in the cosmos, *making generalisations* or principles about patterns or regularities of these particulars, and *generating from these principles new particulars* capable of being *tested*. They are consistent with many views of science in the summary statements, such as forming *conceptual generalisations from the many particulars of empirical evidence* (summary statement 11) and *understanding expressed in laws or principles of greatest generality and which are capable of experimental test* (summary statement 9). Their recurrent and varying use in characterisations of a western European scientific tradition is a useful organising concept in identifying activity as a characteristic of a scientific tradition.

An example of a thematic interpretation of such a tradition is given by Oldroyd’s detailed history of the philosophy and methodology of science (Oldroyd 1989). That account presents a ‘venerable tradition’ (p. 4) of a two-way set of logical processes:

... a model of the process of scientific inquiry which I have called the ‘arch of knowledge’. According to this model, by induction from the world of observed ‘facts’ (phenomena or data) one rises to scientific ‘principles’; and from these principles deductions are made to other ‘facts’, which can be tested experimentally, so that the whole ‘structure’ achieves a certain strength and security. This model, which might also be referred to as a hypothetico-deductive description of science, has been remarkably resilient in the history of ‘Western’ science, and in tracing its history and its numerous historical variants, we have been able to handle a good deal of the historical metascientific literature with considerable economy of thought. (Oldroyd 1989, p. 363)

A few examples only will suffice to indicate the role of these reasoning activities in characterising this tradition, in particular the periods of antiquity, the scientific revolution and twentieth-century science commonly addressed in abbreviated histories. The following have been selected because (1) they illustrate the use of activity in characterising an historical tradition, (2) their common reference in general accounts indicates their significance as key indicators, and (3) they remain current in contemporary
metascientific arguments, either directly or as historical antecedents necessary to understanding the positions in current points of view.

The notion of a two-fold pathway of constructing general principles and reasoning from them was first made by Plato (Oldroyd 1989, p. 25) and first set within a general system of natural philosophy by Aristotle. In this context the methodologies of Plato and Aristotle are portrayed commonly as the archetypical approaches emphasising reasoning and sensing, respectively. At the time of the Scientific Revolution and subsequently, these notions were developed by rationales for induction and deduction in the respective methodologies of Francis Bacon and Rene Descartes, in Newton’s work, and in developments of methodologies associated with empiricism, positivism, rationalism, idealism and experiment. In the twentieth century, science has been characterised partly by the revisionism from several quarters that has invigorated the competition between different viewpoints that draw partly on this two-fold pathway. It is interpreted as a tradition because these and other writers refer to the works of earlier thinkers in such a way that the ideas became the subject of debate, that is, were accepted with the understanding that they could be revised.

For Plato, the material world accessible to our senses is changing and therefore unreliable. True knowledge is knowledge of the Ideas of Forms, the unchanging and immaterial reality behind the material world, and this knowledge is gained by a reasoning process of subjecting concepts to ‘a rigorous process of dialectical discussion’ (Oldroyd 1989, p. 12). By this process successively higher principles are each secured in turn by argument, although exactly how this is done is not clear, as the ongoing ‘problem of induction’ attests (see section 5.4 below). Knowledge of the material world is gained by a ‘descending, deductive, explanatory procedure’, in the manner of geometric proofs (Oldroyd 1989, p. 14).

Aristotle proposed a clearer and more coherent methodology for reasoning both from particular instances to generalisations (induction) and from generalisations and initial statements to particular statements (deduction). Contrary to Plato, Aristotle believed the real world to be that which is accessible to the senses. He therefore proposed (in the Posterior Analytics) that knowledge of Nature was to be gained by investigation based on observations or sense data: that the mind can recognise similarities between different objects and so progressively group them into classes, creating a scientific taxonomy. In the Prior Analytics, Aristotle proposed his well-known syllogistic logic, in which a conclusion is deduced from two assumed propositions or premises:

<table>
<thead>
<tr>
<th>Form of syllogism</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>All A’s are B</td>
<td>All marsupials are mammals</td>
</tr>
<tr>
<td>C is A</td>
<td>Wallabies are marsupials</td>
</tr>
<tr>
<td><strong>Therefore</strong></td>
<td><strong>Therefore</strong></td>
</tr>
<tr>
<td>C is B</td>
<td>Wallabies are mammals</td>
</tr>
</tbody>
</table>
This form of argument is logically correct, whether or not the premises are correct or
even believed to be so, as in this example:

- All A's are B  All marsupials wear socks
- C is A  Wallabies are marsupials
- Therefore  Therefore
- C is B  Wallabies wear socks

Conversely, the form or argument below is logically incorrect, even when the premises
may be true:

- Some A's are B  Some mammals are marsupials
- All C's are A  All dogs are mammals
- Therefore  Therefore
- C is B  All dogs are marsupials

Thus this form of argument tests the validity of the argument but not the truth or
otherwise of its basic premises. Aristotle was thus able to codify the valid and invalid
syllogistic inferences, a technique that has remained useful, if limited. Arguing as it does
from premises, deduction does not claim to generate new knowledge, but it does allow
some claims of truth to be demonstrated. Aristotelian natural philosophy remained the
dominant methodology in Western Europe until about the seventeenth century, with
developments up to that time largely comprising adjustments to and commentaries upon
Aristotle.

The Scientific Revolution is partly characterised as such in terms of the many
developments in methods of inquiry. These include rudimentary developments of logics
of experiment by Francis Bacon (1561-1626), Isaac Newton (1642-1727), David Hume
and John Herschel (1792-1871) (Bhaskar 1983c, p. 137), in addition to the technical
developments noted above and theoretical developments below. The works of Francis
Bacon, Rene Descartes (1596-1650) and Isaac Newton are sufficient to indicate the
development of these activities.

Bacon was strongly influential in establishing an empirical characteristic of science,
meaning that science relies on observation. His major work, the Novum Organum (New
Organon, published in 1620) contained the first comprehensive formulation of induction
as a methodology. Like Sextus Empiricus (c250AD) Bacon recognised that the
syllogisms comprising Aristotle’s deductive reasoning did not lead to new knowledge.
He also recognised the limitations of induction by simple enumeration, that is,
generalising about a class based simply on collecting information about the individuals in
it (Oldroyd 1989, p. 60). Instead, he set out a more thoroughgoing process of induction
which incorporated a very wide basis of observations from which principles are
formulated inductively and tested regularly and securely:

But it was Francis Bacon who most elegantly called for the experimental
interrogation of Nature. In order to establish the ‘inductive ascent’ he envisaged,
Bacon realised the need to differentiate accidental from essential (or necessary)
correlations and to decide between alternative hypotheses for the data. To these
ends, he recommended drawing up Tables of Presence, Absence and Degrees of
factors, and listed various 'prerogative instances' - of which the most famous is the 'Instance of the Fingerpost' or crucial experiment. (Bhaskar 1983c, p. 137)

In turn, these low level principles become the bases for further inductive inferences, leading to higher-level principles of increasing generality. At every level, the principles so formed are subject to deductive inferences, although Bacon paid less attention to this process. Bacon's method offered no recipe for making a sure inductive ascent, nor how any particular answer could be obtained uniquely.

In contrast to Bacon's emphasis on induction are the metascientific writings of his French contemporary, René Descartes (1596-1650). Descartes (in his writings but not his practice) begins with propositions which he believes to be certain, thus eliminating any inductive ascent, and then reasons deductively. This represents an extreme rationalism. Descartes' point of certainty was his certainty in his own existence (Cogito, ergo sum, 'I think, therefore I am'). He then argued that he could hold a similarly 'clear and distinct' notion of God and, by analogy, other 'clear and distinct' ideas such as of substance and space. From such clear and distinct ideas other principles were then derived by deductive argument.

Isaac Newton did not write expressly or extensively as a metascientist, but his success as a scientist has caused considerable interest in his methodology. Newton proposed that scientific activity be a combination of inductive and deductive processes, in a manner that Oldroyd (1989, pp. 79ff) has interpreted as the almost paradigmatic example of his 'arch of knowledge'. This is set out in the 31st Query of the Opticks (1704) as a two-way schema of activities. From observations of and experiments with compounds, motions and effects, generalisations or principles are formed of ingredients, forces and causes, by the process of induction. Then from these principles, other phenomena are explained and the explanations proved, by the process of deduction. It is put succinctly as one of the four 'Rules of Reasoning in Philosophy' in the third edition of the Principia in 1687:

In experimental philosophy we are to look upon propositions inferred by general induction from phenomena as accurately or very nearly true, notwithstanding any contrary hypotheses that may be imagined, till such time as other phenomena occur, by which they may either be made more accurate, or liable to exceptions. (Isaac Newton, as quoted by Oldroyd 1989, p. 82).

This notion of the revisability of scientific claims seems to have been lost in many of the positivistic accounts of science popular in the twentieth century, even in the treatments of Newtonian science given in school and undergraduate levels of science study. Yet here is Newton arguing what post-positivist views of knowledge now claim!

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2 The extent to which Bacon believed his method generated sure knowledge has been the subject of much metascientific debate. (Oldroyd 1987, pp. 65-6)

3 We would now say tested, confirmed or something similar, because recent post positivist metascience rejects the idea that something can be proven.
Newton’s significance in a western European scientific tradition is judged therefore not just in terms of his experimental and theoretical activities, but also his contribution to methodology:

Thus Bacon and Descartes - prophets of a scientific civilisation, rebels against an ignorant past, and zealous students of nature - proclaimed the twin epistemological bases of the modern [Western] mind. In their respective manifestos of empiricism and rationalism, the long-growing significance of the natural world and the human reason, initiated by the Greeks and recovered by the Scholastics, achieved definitive modern expression. Upon this dual foundation, philosophy proceeded and science triumphed: It was not accidental to Newton’s accomplishment that he had systematically employed a practical synthesis of Bacon’s inductive empiricism and Descarte’s deductive mathematical rationalism, thereby bringing to fruition the scientific method first forged by Galileo. (Tarnas 1991, p. 280)

These developments in method and methodology flourished as variants of the two-fold pathway of reasoning, in a tradition of argument and speculation down to the twentieth century. Variants emphasising sensing or perception as the basis for scientific knowledge, following Bacon, are generally interpreted as the development of the tradition of empiricism, and especially the logical empiricism and logical positivism that were very influential in the first half of the twentieth century. Variants emphasising reason as the basis for scientific knowledge, following Descartes, are generally interpreted as the development of the traditions of rationalism, or a priorism or idealism.

Indications of these two themes are given in the empiricism of David Hume (1711-76) and the idealism of Immanuel Kant (1724-1804) although, as we shall see, there is some common ground even here. Hume’s contributions to empiricism are probably best known for his emphasis on sense experience as the basis for knowledge, and the rejection of induction as the basis for certain knowledge:

According to Hume sense impressions are the sole source of knowledge of matters of fact. (Hume included among ‘sense impressions’ desires, volitions, and feelings, as well as visual, auditory, tactile, and olfactory data). He thus echoed Aristotle’s dictum that there is nothing in the intellect which was not first in the senses. Hume’s version (1748) was that ‘all our ideas are nothing but copies of our impressions, or, in other words, that it is impossible for us to think of any thing, which we have not antecedently felt, either by our external or internal senses.’ …

Hume’s analysis has been interpreted as reinforcing Baconian inductivism, a tradition that perhaps as much to Hume’s epistemological investigations as to the counsel of Francis Bacon himself. Thus interpreted, Hume has been held to claim that science begins with sense impressions and can encompass only those concepts which are ‘constructed’ somehow out of sense data. Such a view is consistent with [Newton’s inductive] Method of Analysis, but not with Newton’s axiomatic method. (Losee 1980, p. 104)

Note that Losee identifies even in Hume some sort of activity in which knowledge is constructed from sense data.

Kant, on the other hand, explicitly proposed that the activity of mind is to structure and not simply receive sense data:
For in Kant’s view, the nature of the human mind is such that it does not passively receive sense data. Rather, it actively digests and structures them, and man [sic] therefore knows objective reality precisely to the extent that reality conforms to the fundamental structures of the mind. The world addressed by science corresponds to principles in the mind because the only world available to the mind is already organised in accordance with the mind’s own processes. All human cognition is channelled through the human mind’s categories. The necessity and certainty of scientific knowledge derive from the mind, and are embedded in the mind’s perception and understanding of the world. They do not derive from nature independent of the mind, which in fact can never be known in itself. What man knows is a world permeated by his knowledge, and causality and the necessary laws of science are built into the framework of his cognition. Observations alone do not give man certain laws; rather, those laws reflect the laws of man’s mental organisation. In the act of human cognition, the mind does not conform to things; rather, things conform to the mind...

Thus man does not receive all his knowledge from experience, but his knowledge in a sense already introduces itself into his experience in the process of cognition. Although Kant criticised Leibniz and the rationalists for believing that reason alone without sense experience can calculate the universe (for, Kant argued, knowledge requires acquaintance with particulars), he also criticised Locke and the empiricists for believing that sense impressions alone, without a priori concepts of the understanding, could ever lead to knowledge (for particulars are meaningless without general concepts by which they are interpreted). (Tarnas 1991, pp. 343-5)

Note that these accounts of Hume and Kant indicate a more complex position than would a simple label such as empiricist or rationalist, which in part is Oldroyd’s theme in tracing the subtleties of this complex tradition. Note also the references in each case to other thinkers, indicating the place of these viewpoints as part of an historical tradition.

In 1830 John Herschel proposed a two-way methodology in his *Preliminary Discourse on Natural Philosophy*, namely the distinction mentioned above between the activities in contexts of discovery and justification:

One of Herschel’s important contributions to the philosophy of science was a clear distinction between the ‘context of discovery’ and the ‘context of justification’. He insisted that the procedure used to formulate a theory is strictly irrelevant to the question of its acceptability. A meticulous inductive ascent and a wild guess are on the same footing if their deductive consequences are confirmed by observation. (Losee 1980, pp. 115-6)

Herschel’s account influenced a number of subsequent scientists and metascientists who made significant contributions to this scientific tradition, and we will return to it in the discussion of the contexts of discovery and justification, below.

This theme of a twofold pathway remains evident into the twentieth century, in the early rise of positivism and variations and reactions to it as the century unfolded. Thus Ernst Mach (1838-1916) also rejected the need to suppose an external reality, claiming that scientific knowledge was empirical, relying on the sensations of the observer. The peak influence of positivism came with the variants known as the RV (Suppe 1979). It conflated sensationalism, as proposed by Mach, the correspondence of language propositions with phenomena, as proposed by Bertrand Russell and Ludwig
Wittgenstein, and the dichotomy between empirical and analytical truths\(^4\), as proposed by Hume:

The Vienna Circle aggressively employed Hume’s rigid dichotomy between analytical and empirical truths in the form of a criterion of meaningfulness, which also served as a principle to demarcate scientific from non-scientific discourse: the famous verifiability principle, initially stated by Schlick as ‘the meaning of a proposition is the method of its verification’. (Bhaskar 1983i, p. 334)

The RV dismissed the context of discovery as a concern of science, a position usually attributed to Hans Reichenbach (1938). Not all methodologies of this time placed as great an emphasis on induction. The view of Albert Einstein (1879-1955), for example, was that axioms or principles are \textit{formed}, from which theorems are \textit{deduced} mathematically and then \textit{tested} experimentally. While agreeing that the axioms should correspond to empirical data, Einstein denied that they could be derived directly or logically from it. Instead, the axioms are \textit{formed creatively} (Oldroyd 1989, pp. 273-5). Karl Popper (1902-94) proposed a highly influential variant of this group of methodologies, in which, again, the hypothesis is formed by \textit{conjecture}, but is then \textit{tested} experimentally to be \textit{falsified} (Oldroyd 1989, p. 301). The absence of induction in these accounts follows from objections to induction, which is explored below in section 5.4 on the problems of induction.

5.4 Problems with induction

We have noted that induction as variously interpreted has been an enduring concept of scientific activity in a western European scientific tradition. Indeed, it remains a plausible way to build a commonsense view of the world: it seems quite reasonable to expect that the sun will rise tomorrow, for example. We have noted also, however, that Hume established an objection to induction. This difficulty is now part of a more complex metascientific issue concerning the explanation and justification of induction (Chalmers 1982), the main features of which are sketched here.

The first set of problems may be taken as arising from within the notion of induction itself. Induction is taken generally as a process of reasoning by which general statements or propositions are established from a number of particular instances (Cohen 1983, p. 203). A simple view of induction is summarised by the statement,

\textit{All X's observed have the property Y, therefore all X's have the property Y.}

\(^4\) The general distinction is that analytic statements are true because of the meanings of the words in it, like All bachelors are unmarried, whereas synthetic statements are true because of the way things are in the world. Analytic statements are held by many to describe mathematical knowledge, and synthetic statements to describe empiricist knowledge, although there are philosophical flaws in this distinction (Bostock 1983, p. 16).
Statements of this sort include,

\textit{All swans are white.}

\textit{Acids turn litmus paper red.}

As Chalmers has pointed out, the reasoning that produces this sort of statement is appealing in several respects:

[I]t gives a formalised account of some of the popularly held impressions concerning the character of science, its explanatory and predictive power, its objectivity and its superior reliability compared with other forms of knowledge. (Chalmers 1982, p. 10)

There are several objections to any claim that induction produces certain knowledge, however. First, induction is not supported by an appeal to logic: the premises may be true and the conclusion false without logical contradiction. The example of the white swans is well known: on the basis of a very large number of observations over a long time that swans are white, Europeans concluded that all swans are white, only to find black swans in Australia. Secondly, induction is not supported by an appeal to experience of successful inductions. The argument,

\textit{The principle of induction has worked successfully on a very large number of occasions, therefore the principle of induction always works},

is a circular argument: it is an argument by induction. This is the problem of induction, well known in philosophy and demonstrated by David Hume (Chalmers 1982, pp. 13-5). Thirdly, several paradoxes can be constructed within inductive logic, which indicate difficulties with constructing hypotheses suitable for inductive evaluation. One example is the \textit{paradox of the ravens}, by which Hempel showed that two logically equivalent hypotheses based on the same empirical data, such as

\textit{All ravens are black}

and

\textit{All non-black things are non-ravens}

seem to lead to a non-black thing such as a white handkerchief confirming that all ravens are black! (Cohen 1983, p. 204)\textsuperscript{5}. This represents a difficulty in confirming or

\textsuperscript{5} The ravens paradox arises by invoking three principles (Achinstein 1993). (1) On Nicod's Principle, for the hypothesis \textit{All ravens are black}, instances of black ravens are confirming evidence and instances of non-black ravens are disconfirming. (2) On the Equivalence Principle, instances of black ravens are confirming evidence for the hypothesis \textit{All ravens are black}, and they are also confirming evidence for the logically equivalent hypothesis \textit{All non-black things are non-ravens}. (3) By a principle of deductive logic, the type of inference called modus tollens, the statement \textit{If raven then black} leads to the valid statement \textit{If not black then not raven} (Walton 1993, p.214). If the observed non-black things are, for example, a white handkerchief and red shoes, then by (1) they confirm \textit{All non-black things are non-ravens}, which by (3) is logically equivalent to \textit{All ravens are black}, and therefore by (2) confirm \textit{All ravens are black}! The solution is not agreed.
supporting hypotheses, for which there is not yet a generally agreed answer (Achinstein 1993; Blackburn 1983c).

Another example is the *new riddle of induction*, proposed by Goodman in 1954:

The classical problem of induction searches for our right to project from the features we have observed things to possess, when we expect similar things to exhibit similar features in cases outside our observation. The new riddle concentrates rather on selection of certain features as fit for projection. It alleges we can in principle classify things so that events would exhibit breakdown of uniformity, instead of exhibiting the continuation of regularity. Thus both change or uniformity can be somehow relative to a particular, optional, conceptual scheme, or psychological or linguistic background. If so, the old problem of induction becomes yet more intractable, since there could be no *a priori* reason for expecting the world to conform to one scheme of description rather than another. Goodman’s critics have tried to show the concept of a change or a uniformity is not in this way subjective, since we have no coherent concept of what it would be to operate the alleged alternative schemes. (Blackburn 1983b, p. 299)

That is, the classical criticism of induction relates to the conclusion containing more information than the premises, and Goodman has added the criticism that induction appears to rely on how we interpret the cosmos (which the present thesis interprets as relying on a particular belief system).

A broader set of problems concerning induction applies to some other accounts of methodology as well. Central to most of these is the view, now widely supported, that observations are *theory-laden* or *theory-soaked* (Chalmers 1982, ch. 3). Methodologies that strongly advocate induction, such as the positivist RV, hold that scientific activity started with observations and that scientific observations were objective and value-free. Post-positivist accounts, however, argue firstly that observations are not simple neural receptions such as retinal images; they are shown easily to be subject to interpretation, as in optical illusions. Secondly, the formulation of public observation statements from internal subjective experiences of the observer, as required by the logical positivists, means using a public language and conceptual scheme that belong to some theory. This means that theory is prior to observation, the opposite of a strict approach to induction. Thirdly, says Chalmers, observation and experiment are not unbiased, but are themselves guided by theoretical assumptions. The present thesis interprets the prior role of theory to mean that observations are made so that they are consistent with the belief system of the observer. In a looser sense, observations have been shown to be influenced by a wider set of factors, including social, personal and other contexts, as discussed in Appendix B.1 on context. Fourthly, some alternative accounts do not employ induction at all. The best known of these is probably Popper’s methodology, which says that scientists arrive at hypotheses by *conjecture*, and then seek to *refute* or *falsify* them; it does not require induction.

There are two other main possible responses to the problem of induction. One is to reject the claim that methodologies are rational. The sceptical approach of Hume is that if
Appendix B.5: Activity

induction cannot be logically justified and science is inductive, then science is not rational. Hume’s answer was to argue that what we interpret as inductive theories are instead habits of mind following repeated experiences. Alternatively, the anarchical approach of Feyerabend holds that no methodology proposed has explained scientific activity, so scientists should not be concerned with methodologies; hence his well-known (and contested!) conclusion that ‘anything goes.’ Another response is to propose alternative methodologies that do not rely on induction, which is the approach advocated by Chalmers.

There are some defences of induction. The objections above are not an absolute refutation of induction (Chalmers 1982, p. 35). Other metascientific accounts also have their difficulties and debate continues over the nature of scientific activity. Some would argue that the theory-laden-ness of observations is not as significant as claimed by post-positivist metascientists. Some inductivist accounts lessen the requirement for the generalisation to be true, requiring instead that it be probably true given a large enough sample of observations. Although logical problems remain for probabilistic accounts, at least some sort of sophisticated induction retains some appeal. Significantly, induction is nonetheless the means scientists and others use to collect and order empirical data:

But Popper’s critics have pointed out that the rational exploitation of scientific discoveries is impossible without some reliance on a method of grading the support that evidence gives to theory. (Cohen 1983, p. 204)

A shift in interpretation of processes: inductivism to hypothetico-deductivism

The objections to induction account for some of the shifts noted in the two-fold pathway described by Oldroyd, above. The two-fold reasoning exemplified perhaps by Francis Bacon and Newton is described in the literature as the methodology inductivism:

Inductivism is a point of view that emphasises the importance to science of inductive arguments. In its most inclusive form, it is a thesis about both the context of discovery and the context of justification. With respect to the context of discovery, the inductivist position is that scientific inquiry is a matter of inductive generalisation from the results of observations and experiments. With respect to the context of justification, the inductivist position is that a scientific law or theory is justified only if the evidence in its favour conforms to inductive schema. (Losee 1980, p. 148)

Inductivism is one of the two main historical variants, or group of variants, of this two-fold reasoning. The other term is hypothetico-deductivism which seems to have two interpretations. In its narrower sense it rejects induction: a hypothesis is formed by conjecture or guessing and followed by deductive reasoning. In its broader sense it allows the construction of the hypothesis by whatever means, induction or conjecture, followed by deductive processes. The broader use can be seen in Oldroyd (1989), as in the quotation from Oldroyd (1989, p. 363) above, and in an earlier footnote:
... the formulation of hypotheses, the working out of the empirical implication of these, and the testing by experiment and/or observation (Oldroyd 1989, p. 46, n.107)

and in Porter (1988):

Popular in the middle of this century was hypothetico-deductivism, the notion that facts should lead to hypotheses which would guide further investigation leading to further investigation leading to the testing of hypotheses, and so forth, in a progressive manner. (Porter 1988, p. 760)

The narrower sense is more specific about the initial or 'upward' pathway to the hypotheses:

[Hypothetico-deductive method] ... is based on the idea that hypotheses cannot be derived from observation, but once having been put forward (as a result of an imaginative leap) may be tested against observation. (Richards 1983a, p. 196)

This approach describes the methodologies of Einstein and Popper, mentioned above in Oldroyd's account. Whichever version is advocated, hypothetico-deductivism fits within the broader tradition identified by Oldroyd as one of a range of attempts to discern some underlying order in the many observed particulars, and to use this perceived order as the basis for extending our knowledge by testable predictions.

5.5 The characterisation of key metascientific viewpoints by activity

Reasoning activities and methodologies are part of the characterisation of metascientific viewpoints. This was foreshadowed in the preceding historical discussion, in which metascientific viewpoints such as rationalism/a priorism and empiricism were partly characterised by their differing accounts of scientific activity. Activity as a dimension of science is useful, therefore, in characterising metascientific viewpoints:

All of the stock appreciations of scientific knowledge - as objective (logical empiricism), as relative to culture (Kuhn, Feyerabend), as relative to interests (SSK) - can be translated into particular understandings of scientific practice. We can move in the opposite direction too, and it is an interesting challenge to read new understandings of practice back into the problematic of knowledge ... Likewise we can read studies of practice back into social theory and historiography. (Pickering 1992c, p. 7)

Table B.5.1 sets out six metascientific analyses showing how different metascientific approaches in the literature characterise science by activity. Each analysis categorises a variety of viewpoints identified by the author, and the differences between them give some indication of the differences between metascientific views, at least as they characterise science by activity.

The centrality of empirical activity

Before discussing differences of view, we should note that there is general recognition that experience is an essential characteristic of science, even though different accounts focus on various other activities, and interpret empirical activity variously:
Despite [other differences], few modern philosophers would want to deny the epistemic value of experience - the central insight of empiricism - or the ideas that at least some terms in a theory must be partially empirically defined or that law-like statements are ultimately to be judged by their instances under experimentally produced and controlled conditions. (Bhaskar 1983b, p. 121)

Metascientific characterisations by activity

The comparison of metascientific views follows the format used in each of the six companion chapters. Thus we interpret three main positions in the post-positivist consensus in HPS: constructivism, post-positivist empiricism and scientific realism. (a) In constructivism or neo-Kantianism, the characteristic activity is taken as reasoning or mental construction. Weltanschauungen analyses emphasise the need to consider scientific activity from within its conceptual perspective. In (b) post-positivist empiricism, the characteristic activity is taken as observation, but with less or modified emphasis on induction than positivism advocated. In terms of activity, Suppe (1979) sees positivism as essentially concerned with induction as the means by which knowledge claims are justified or confirmed, and the incorporation by reduction of ‘older theories into more comprehensive theories’ (Suppe 1979, p. 704). In (c) scientific realism, the characteristic activity is taken as description and explanation of an independently existing cosmos. As noted in earlier chapters, there are several variants of realism (Bhaskar 1983b, p. 363). Although realism is based on beliefs about Nature rather than activity, the variants of realism are distinguished in part by the investigative activities of Nature. Thus Platonic realism entails reasoning to ascertain an abstract reality; Aristotelian realism entails observation to ascertain a material reality; perceptual realism entails perception of a material reality which is independent of perceptions; and scientific realism entails perceptions and other activities (including social activities) of scientists, concerning the objects of scientific inquiry.

In STS, Callon’s (1995) review of the field suggests four perspectives. Each model assumes the laboratory/experimental activities of scientists, but posits additional, characterising, activities as necessary for understanding scientific development. Thus, (a) where science is characterised as rational knowledge, the characterising activities are the production and clarification of scientific discourse, that is, ‘statements that are the result of a dialogue between man [sic] and nature’ (Callon 1995, p. 35). (b) Where science is characterised as a competitive enterprise, the characteristic activities are the production

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6 It is worthwhile reminding the reader here that the present thesis urges caution about characterising differences between notional fields such as HPS and STS. For example, we have noted the general assent that empirical activity characterises science. Also, many views in STS and post-positivist HPS accept that, at least to some extent, the individual constructs their personal knowledge, an insight of constructivism or neo-Kantianism. These are labels for different interpretations or characterisations of science, and serve to highlight perspectives and emphases.
and competitive evaluation of scientific knowledge. (c) Where science is characterised as sociocultural practice, the characterising activities are the production of scientific knowledge by socio-cultural as well as epistemic activities and norms. (d) Where science is characterised as extended translation, the characterising activities are the interactions of humans, technical devices and phenomena.

5.6 The notion of a uniform method of science (the Scientific Method)

No discussion of the characterisation of science by activity would be complete without mention of scientific method. It is often referred to as the scientific method, sometimes capitalised, and is usually taken to indicate either explicitly or implicitly the notion that there is a single, standardised method or algorithmic approach for carrying out scientific investigations (see Messel 1964 in summary statement 95). The companion chapter on structure, and Appendix B.4, noted the view of the unity of science was once pervasive and still endures, but is now widely contested, at least in the metascientific literature. What is of particular interest in the present thesis is that the notion of scientific method may be a good indicator of a gap between conceptions of science held, on the one hand, by the general community, school students of science, perhaps undergraduate students of science, and others, and on the other hand recent conceptions of science held by the metascientific communities. We have noted the lack of a single, consensually-held metascientific view since the decline of the RV, but if there is something approaching such a contemporary consensus it is the widespread view that there is not now and was not in history a single, generic method of (investigative) scientific activity. This view is given in summary statement 103 (Holton & Roller 1958) and in more recent characterisations:

Pasteur was a great scientist but what he did bore little resemblance to the ideal set out in modern texts of scientific method. It is hard to see how he would have brought about the changes in our ideas of the nature of germs if he had been constrained by the sterile model of behaviour which counts, for many, as the model of scientific method. (Collins & Pinch 1993, p. 90)

Yet the concept of the scientific method remains in use, sometimes within metascientific writings, and certainly elsewhere. Of course use of the notion of scientific method is a clear example of characterising science by activity, and this alone merits its attention here. Beyond that, though, it serves to illustrate some subtleties of characterisations, which are mentioned below in no particular order.
Scientific method and the unity of science

First, the very notion of a single method rests on an assumption about uniformity of science. The concept of methodological unity is put succinctly by Schuster, in his discussion of differences between interpretations of the Scientific Revolution:

... the universal assumption that modern science has some simply graspable defining feature which, turned into an historical category, invites explanation of the Scientific Revolution through the search for general causes of the appearance, sudden or otherwise, of that feature. (Schuster 1990, p. 221)

That is, it rests on an essentialist view of science. The assumption applies to any interpretations of this type, including the interpretation of scientific activity in terms of a single method: it implies an assumption that various activities in different times and in different contexts can be reduced to a single method. The unity of science, including methodological unity, is discredited in metascience though less so in other forums, as discussed in Appendix B.4.

Scientific activity and the RV

Secondly, the emergence and dominance of the positivist RV early in the twentieth century marked the dominance of a particular, narrowly defined view of methods in science:

The standard, logical empiricist account of scientific method (particularly confirmation theory and concept formation) is largely based on three distinctions...

1. The observational/theoretical term distinction (and the conceptual vacuum analysis of theories to which it leads).
2. The sharp distinction between context of discovery from context of justification.
3. The fact/value distinction, to put it crudely; more accurately, the theory/methodology distinction, which is made to support two doctrines:
   a. theory systems are value-neutral,
   b. methodology is theory-neutral, that is, independent of theoretical developments.

A prominent conclusion, or perhaps assumption, of the standard account is the doctrine of the methodological unity of science, the view that all sciences worthy of the name employ the same methods, logically speaking, of concept formation and theory testing and that theories (and explanations and predictions) have the same structure in all scientific disciplines. Intimately related to the above distinctions, the doctrine of unity of method nevertheless deserves special emphasis... (Nickles 1979, p. 575)

This view allows only a narrow scope of possible activities which would be considered ‘scientific’, and ascribes certain criteria such as value-neutrality. Such a dominant view sets the scope and criteria to which other accounts are pressured to meet if they claim to be ‘scientific’. When the dominant view is normative, setting out what science should be,

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7 See Appendix B.4.
8 See the discussion on boundary work, in the companion chapter on context and Appendix B.1.
as the RV was, it avoids the need to provide a compelling description of actual activity, as
descriptive accounts seek to do. Thus the ongoing influence of the RV, discussed above,
has reinforced this notion of a uniform method in science.

The scientific method and legitimisation in the social sciences

Third is the ongoing recourse to the scientific method by some of the social
sciences and other fields as a means of legitimising or conferring scientific authority (the
authority of the scientific method) upon their own endeavours. To varying extents, this
may be interpreted as representing scientism, or the use of the image of science:

[S]cientism is present where people draw on widely shared images and notions
about the scientific community and its beliefs and practices in order to add
weight to arguments which they are advancing, or to practices which they are
promoting, or to values and policies whose adoption they are advocating.
(Cameron & Edge 1979, p. 3)

For example, Collins and Pinch (1993) have given as examples fields among the social
sciences and anti-science groups which, although their motivations may be different,
nonetheless show recourse to particular notions of scientific method in making their
respective cases:

... The impact of our redescriptions should be on the scientific method of those
disciplines which ape what they take to be the right way of going on in the high-
prestige natural sciences, and on those individuals and organisations who would
destroy fledgling sciences for their failure to live up to a misplaced ideal.

Notoriously, the social sciences suffer from the first malaise - physics envy,
as it is known - with areas of experimental psychology and quantitative
sociology, all pedantically stated hypotheses, and endless statistical
manipulation of marginal data, being the most clear-cut examples of this kind of
'scientism'.

The second malaise is more worrisome. The favourable public reception of
unusual sciences such as parapsychology ... has given rise to fears that fringe
sciences are taking over. An anti-fringe science movement has been spawned
whose members take it on themselves to 'debunk' all that is not within the
 canon, in the name of proper scientific method. Where this effort is aimed at
disabusing the public about unsupported claims, it is admirable, but the zeal of
these self-appointed vigilantes carries over into areas where they have no
business.

Recently, on British television, the public at large was able to witness a stage
magician informing a prestigious scientist, head of a famous Paris institute, that
his ideas were ridiculous. The motive for this attack was not the professor's
methods but the topic he had chosen to research - homeopathy; the instrument
of the attack was, nevertheless, an idealised version of what scientific method
ought to be. It is no coincidence that those who feel most certain of their grip on
scientific method have rarely worked on the frontiers of science themselves.
(Collins & Pinch 1993, p. 143)

That is, the grounds for attacking the work of the scientist was a simplistic
characterisation of scientific activity, even though the subject of the attack was the topic
or cognitive content. This is an attempt to mark a boundary between science and non-
science, and is an example of arguments concerning boundary issues.
We could add educational research as a collection of fields that have drawn on the scientific method also:

... Compared to other sources of knowledge, such as experience, authority, inductive reasoning, and deductive reasoning, application of the scientific method is undoubtedly the most efficient and reliable ... Although neither inductive nor deductive reasoning is entirely satisfactory, when used together as integral components of the scientific method, they are very effective ... The scientific method is a very orderly process which entails a number of sequential steps ... (Gay 1976, pp. 4-5).

Even in 1976, this characterisation was appealing to a view of science that in metascience at least was declining and largely abandoned. There is less excuse in later examples, when the tenor of metascientific debate was not only to have rejected the scientific method, but to have moved on to new issues. For example, Halliday and Martin (1993) cited the same passage from Messell (1964) quoted in summary statement 95 as the authority for discussion of method in school science texts, which undermines their subsequent analysis of the linguistic features of science (Halliday & Martin 1993, pp. 183ff). Even science texts are no guarantee of metascientific currency: Kormondy and Essenfeld gave a step-wise recipe-like account of ‘the scientific method, which is a logical way of solving problems’ in their senior secondary school science text Biology, although they concluded with the unsupported disclaimer that ‘scientists do not always follow the scientific method exactly, but they are guided by it’ (Kormondy & Essenfeld 1984, pp. 96-7).

A weaker version of scientism is the passing or simplistic mention of scientific method, thereby either inferring or endorsing the notion of a single, generic method. It is surprising to find this type of mention in books, recent and widely regarded as authoritative, written to popularise and demystify late-twentieth century science:

The success of the scientific enterprise can often blind us to the astonishing fact that science works. Although most people take it for granted, it is both incredibly fortunate and incredibly mysterious that we are able to fathom the workings of nature by use of the scientific method (Davies 1992, p. 148, emphasis added; see also Davies in summary statement 120).

**Historical references to multiple scientific methods**

Fourthly, we may add that there have been many references historically to the diversity of approaches to scientific investigation; there is and has been no single and universally endorsed authority of scientific method, despite the authoritative tone of Francis Bacon’s seminal writings on scientific inquiry. This is mentioned in general histories of science that in other respects are sometimes interpretively dated (Sarton 1936; Singer 1959). Also, Holton and Roller (1958, pp. 248ff) have cited specific examples: the identification of the role of chance by Joseph Priestley (1776) and W. I. B. Beveridge (1951); the plurality of methods and approaches by P. W. Bridgman (1950); of method as the extension of common sense by Max Planck and others; the appeal at some stage,
but not always at the same stage, to experiment and observation, such as by Francis Bacon and Galileo Galilei; and the appeal to creativity and intuition, rather than logic, as found in Plato, Galileo and Einstein. Holton and Roller interpreted this mix of characteristics of method in terms of 'outlook' or 'orientation' or 'attitude' (1958, p. 252), which the present thesis interprets as elements of belief system. One might presume that the rejection of this advice for much of the twentieth century has been due to the dominance and lingering influence of the positivist RV.
5.7 Interpretations of some characteristic scientific activities

Another example of the metascientific variation in accounts of scientific activity is that there are different accounts of any one activity. The present section discusses experiment, observation, explanation and prediction as activities by which science is commonly characterised, but which themselves are characterised variously in the literature.

5.7a. Experiment

Probably foremost in the public image of scientific activity, and even for many the defining activity, is the experiment. In standard scientific texts experiment is defined in terms of controlling the conditions under which observations are limited to particular phenomena:

An experiment usually consists in making an event occur under known conditions where as many extraneous influences as possible are eliminated and close observation is possible so that relationships between phenomena can be revealed. (Beveridge 1953, p. 13)

Typically the experiment is represented in terms of its role among the other activities of a research project, such as reviewing the literature, collecting data including field or laboratory observations, organisation of the data collected and determination of the problem and specific research questions, making informed guesses, forming and considering hypotheses, and devising experiments 'to test first the likeliest hypotheses bearing on the most crucial questions' (Beveridge 1953, p. 12). In some accounts it is not clear whether or not the term experiment is used to include some of these extra activities, in the sense of being general investigative activity. In either case, experiment is presented in these accounts as being relatively unproblematic except for methodological issues: the chief concerns in experimenting are usually given as selecting and executing the appropriate scope and sequence of activities.

Experiment is a significant element in characterisations of science in several respects. First, it is significant historically. The experimental successes beginning from about the seventeenth century were a marked improvement on Aristotelian methodology, and an even greater contrast with the scholastics' neglect of Aristotle's emphasis on observation:

The important point, of course, is that the new philosophy claimed that new knowledge was to be obtained by experimentation, not by analysis of language or by establishing the correct definition of things. If you wanted to know more about the properties of gold than anyone had ever known before you would need a chemical laboratory, not a dictionary! (Oldroyd 1989, pp. 91-2).

Secondly, the experiment not only remained current in science, but central to it:
Here we have again the persistent and striking *leitmotif* in science, the appeal to *observation and experiment as last authorities*. (Holton & Roller 1958, p. 251; emphasis in original)

Thirdly, the notion of the scientific experiment has passed into the public domain, where *experiment* has a quasi-scientific meaning as any ‘test or trial’ (*The Macquarie Dictionary*), and remains current among the general public as a characteristic activity of scientists. Fourthly, it is a concept of continuing interest in metascientific debate, as the following discussion shows.

*Theory and experiment*

There has been long-standing metascientific interest in the relationship between experiment and theory (Bhaskar 1983c), of which Hacking (1983) is critical because of the historical preference for examining theory. The popular characterisation of scientific observation as being objective arises particularly from the RV of science, in which observation is given as unbiased or free of theoretical influence; that is, experiment precedes theory, where experiment is interpreted generally, as investigative activity. In post-positivist metascience, there is considerable acceptance that observations are *theory-loaded* (the term being attributed to Hanson, 1958); that is, theory precedes experiment. Hacking (1983, pp. 150ff) has given historical examples of two roles envisaged for experiment, as defined by its relationship to theory. Thus in the essentially inductive view given by the chemist Sir Humphry Davy (1778-1829), experiment precedes theory: new facts are discovered through experiment and analogies confirmed by it. However, in the essentially deductive view given by the chemist Justus von Liebig (1803-73), experiment follows theory: thoughts or theories are tested by experiment.

Hacking (1983, pp. 152ff.) has cited a variety of historical examples that demonstrate different relationships between observation, as a component of experiment, and theory. Thus, for example, experimental results have been recorded, if not independently of, then certainly in advance of explanatory theory, such as the work of E. L. Malus (1775-1812) on polarisation by reflection, John Herschel (1792-1871) on fluorescence, and the observation of pollen movement in water by Robert Brown in 1827. Alternatively, experimental and theoretical work have commenced quite independently and have been brought together to their mutual benefit, such as the measurement of (unexplained) background radiation in space by Arno Penzias and R. W. Wilson in 1965, and the contemporaneous theorising by a group at Princeton that a Big Bang origin of the universe should have resulted in measurable background radiation. And theory has preceded experiment in new fields of science, such as the development of the theory of electromagnetism by A. -M. Ampère (1775-1836). Collectively these examples support the view that seeking to determine the order of the two may less productive than pursuing other elements of characterisation.
Another difficulty with the notion of theory arising from or being tested by experiment is that any one theory can be shown to be dependent on multiple auxiliary theories. Auxiliary theories are used in the design and construction of the apparatus and the experiment, and in the interpretation of the results and which in turn need explication (Bhaskar 1983c, p. 138). This follows 'Duhem's doctrine that a theory inconsistent with an observation can always be saved by modifying an auxiliary hypothesis, typically an hypothesis about the working of an instrument' (Hacking 1992, p. 30). For example, the notion of replicating experiments, for the purposes of increasing accuracy or checking the validity of claims, is widely held to be essential in science, yet assumptions about the reproducibility of experimental conditions are problematic. Replication experiments often differ minutely from the original to 'improve' results or reliability, and in any event it is difficult to claim that the initial conditions were precisely reproduced. This is most significant, and evident, when 'the very existence of the phenomenon is itself in doubt', where the design of the experiment and even the apparatus depend on the very theoretical assumptions being tested. This is notable in biology, psychology and parapsychology but there are also examples in physics, such as the search for gravitation waves (Collins 1983, p. 372).

Some current issues concerning experiment

The current status of the experiment is the subject of interest from several quarters, largely concerning the set of assumptions and beliefs underpinning the experiment (Bhaskar 1983c; Shapere 1984; Knorr Cetina 1995). Thus the expertise, prior beliefs and prior theories held by experimenters and observers are factors which influence experiment, a conclusion rarely recognised by experimenters and observers. This has meant identifying and questioning the belief system (assumptions and beliefs about the cosmos and appropriate ways to gain knowledge of it), purposes, contexts (psychological, socio-cultural and ontological) and procedures involved in experiments:

An experiment, unlike an experience, is a designed practical intervention in Nature: its upshot is a socially contrived set of observations, carried out under artificially produced and deliberately controlled, reproducible conditions. At the experiment's core is the notion that the conditions for producing a given effect can be separated into independently variable factors, in such a way as to demonstrate how the factors behave in their natural (ie. the non-experimental) state. The crucial assumption is that the factors studied - and represented in experimental design as independent and dependent variables - retain their identities (and dispositional properties) whether or not other conditions are held constant, as in the laboratory, or freely vary, as in extra-experimental reality. (Bhaskar 1983c, p. 136)

This is a much clearer distinction between the controlled intervention and other kinds of data gathering or observational activities.

Secondly, there has been a re-evaluation of the role of experiment in science, especially in the genre of laboratory studies within STS. The traditional methodological
account of experiments served to demonstrate validity and rationality of scientific activity and the knowledge it produced:

[Experiments ... have until recently carried much of the epistemological burden in explaining the validity of scientific results and rational belief in science. They provided the frameworks within which 'the scientific method' was deployed and bore fruit. They were the units in terms of which science proceeded empirically step by step, the rungs in a ladder of theory testing and empirical verification. Experiments were largely defined methodologically in earlier studies; notions like the testing of theories, experimental design, blind and double-blind procedure, control group, factor isolation, and replication are all linked to experiments. The advantages attributed to experiments include the fact that they disentangle variables and test each variable by itself, that they compare the results with those of a control group, that they avoid experimenter bias and subjective expectations, and that their results can be justified through replications that 'anyone' can check or perform. With this methodological definition of experiments in place, the real-time processes of experimentation in different fields remained largely unexamined (Goodyng, Pinch & Schaffer 1989). (Knorr Cetina 1995, pp. 142-3)

The shift in the laboratory studies has been to explicate all the activities in the laboratory, not just idealised experiments, with the result that these studies claim that scientific knowledge is 'not only "technically manufactured" [by experiment] in laboratories but also inextricably symbolically and politically construed', by activities such as persuasive techniques in scientific papers, forming alliances and mobilising resources (Knorr Cetina 1995, p. 143).

Thirdly, a feature of some of the laboratory studies in recent decades has been the identification of factors involved in experimental work, often listed as typologies, that indicate strongly that the outcomes of experiments can be affected by a range of factors. Hacking (1992, p.29) has noted the extraordinary amount of empirical knowledge that has accumulated since the seventeenth century, indicating that scientific knowledge and practices seem remarkably resilient, 'modified but not refuted, reworked but persistent'. His explanation is that when the laboratory sciences are practicable, they tend to develop a stable and self-vindicating structure: theories and equipment evolve together symbiotically, which is 'a contingent fact about people, our scientific organisations, and nature' (Hacking 1992, p. 56). Nature does not actively cause the symbiosis; it is merely the agency within which theory and equipment are successfully interdependent. Of course, laboratories are not experiments and experiments are not confined to laboratories.

Hacking (1992, pp. 32ff) has proposed a taxonomy of elements of experiment from which the self-vindicating character of laboratory sciences arises, which demonstrates the 'motley of experimental science', its potential for various outcomes including 'successful' ones, and its 'human agency' - that it is done by people (1992, p. 32). It is this taxonomy in which we are interested as a characterisation of experiment. In brief, Hacking says that experiments are characterised by three groups of elements: ideas, things and marks.
Ideas include both philosophical and pragmatic questions; background knowledge (including beliefs, addressed in the present paper as part of belief systems); systematic theory about the subject matter, and local, topical hypotheses that connect systematic theory to phenomena; and modelling of the apparatus, which are the theories or lore about the design and working of the equipment and instruments used.

The group things includes the target - the substance or population being studied, and its preparation (as in microbiological staining) and modification (as in injecting the prepared cell with a foreign substance); source of modification, usually the equipment that interferes with the target; detectors that determine or measure the result of the modification; tools, a category that overlaps with other categories, but includes the multifarious and often mundane artefacts used in preparing, modifying, and other experimental activities, such as microtomes, chemicals and off-the-shelf items; and data generators, that generate marks and may be detectors, such as cameras, computer scanners, automatic printouts, and people who are counting.

Marks includes data, meaning uninterpreted inscriptions, graphs, photographs, tables or displays; data processing, which includes data assessment (calculation of probable error and estimation of systematic error), data reduction of large amounts of numerical data into manageable amounts or forms, data analysis in terms of specified theories or hypotheses, and image enhancement as in microscopy and astronomy; and finally interpretation of the data. Data assessment and data reduction are supposed, in principle, to be theory-neutral applications of statistical methods, but Hacking argues that often they are not. Data analysis has become more significant in recent decades and, in introducing ‘an echelon of workers or devices between the data and the principal investigators’ has transformed experimental science (Hacking 1992, p. 49).

Hacking’s argument presents a strong case for the inter-connectedness of experiment in science: interconnectedness within experimental elements (such as data interpretations leading to new data reduction, analysis and assessment), with theory in self-vindicating stable sciences, and, more significantly here, with other factors. Other factors include the impact on other theories, following ‘Duhem’s doctrine that a theory inconsistent with an observation can always be saved by modifying an auxiliary hypothesis, typically an hypothesis about the working of an instrument’ (Hacking 1992, p. 30), and the researchers who attend to those. Quite clearly, the outcome of an experiment can be affected by a change in any one or more of Hacking’s elements, as the genre of laboratory studies shows (Knorr-Cetina 1995).

Similar sorts of typologies for understanding experiment have been proposed, which although different in approach and detail, identify a range of factors that, if varied, affect the experimental outcome. Thus Gooding (1992, pp. 67-8) has identified (1) the ‘interaction of hand, eye, and mind in the fine structure of observation’; (2) human agency; (3) unexpected events; and (4) the ‘absence of linear, logical structure’. Knorr-
Appendix B.5: Activity

Cetina (1992) has identified a general approach in laboratory studies that redefines traditional notions of self, others and things such that all human and non-human agents of activity are treated as ontologically equal in order to trace activity thoroughly:

In relevant [laboratory] studies, the laboratory is the locus of mechanisms and processes which can be taken to account for the success of science. Characteristically, these mechanisms and processes are nonmethodological and mundane. They appear to have nothing to do with a special scientific logic of procedure, with rationality, or with what is generally meant by ‘validation’. The hallmark of these mechanisms and processes is that they imply, to use Merleau-Ponty’s terminology, a reconfiguration of the system of ‘self-others-things’, of the ‘phenomenal field’ in which experience is made in science. As a consequence of these reconfigurations, the structure of symmetry relationships which obtains between the social order and the natural order, between actors and environments, is changed. To be sure, it is changed only temporarily and within the walls of the laboratory. But it appears to be changed in ways which yield epistemic profit for science. (Knorr-Cetina 1992, p. 116, and Knorr-Cetina 1995, pp. 144-5)

Critics of laboratory studies object to the undervaluing or omission of criteria of rationality in those studies (Bunge 1991; Bunge 1992; Slezak 1994a; Slezak 1994b)⁹. The present thesis interprets this as failing to account for the belief system. Nonetheless, the argument is compelling that if we are concerned to explicate actual rather than idealised activity in science, then the outcomes of experiments are subject to multiple influences, however interpreted. The argument advanced in the present thesis is that a complete characterisation of science would include criteria of rationality, beliefs, attitudes and so forth, as elements of the belief system held by the investigators, as well as a broader notion of laboratory activity than just idealised experiments.

5.7b. Observation

More so than for experiment, observation is a term which is used non-scientifically at large: to mean the activity of noting, perceiving or watching, but also ‘the information or record secured thereby [or] … that which is learned by observing’ (The Macquarie Dictionary). Observation in science is regarded popularly as similar to any observation, but with particular attention to accuracy; this is developed by specialist training. While a reasonable characterisation at face value, observation is a good deal more problematic than this in a number of metascientific accounts. We will restrict the scope here to two issues particularly significant in characterisations using observation.

Observation and theory

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⁹ There is, nonetheless, a healthy discussion between scientists and metascientists, as in an exchange in the journal Social Studies of Science. See Labinger 1995a; Collins 1995; Fuller 1995; Jasanoff 1995; Hakken 1995; Keith 1995; Lynch 1995; Marks 1995; Pinch 1995; Stockdale 1995; Labinger 1995b
First, there are conflicting views of the relationship between observation and theory (Suppe 1979; Chalmers 1982; Callon 1995). On the one hand, experimental activity produces statements, and on the other, theories are expressed in statements:

According to the inductivist account of science, the secure basis on which the laws and theories that constitute science are built is made up of public observation statements rather than the private, subjective experiences of individual observers. Clearly, the observations made by Darwin during his voyage on the *Beagle*, for example, would have been inconsequential for science had they remained Darwin’s private experiences. They became relevant for science only when they were formulated and communicated as observation statements capable of being utilised and criticised by other scientists. The inductivist account requires the derivation of universal statements from singular statements by induction. Inductive as well as deductive reasoning involves the relationships between various sets of statements and not relationships between statements on the one hand and perceptual experiences on the other. (Chalmers 1982, p. 28; emphasis in original)

However, high-level theories do not refer directly to particular observations; the two groups of statements use different vocabularies. The observational vocabulary, such as *red, touches, hot, longer than* or *cell nucleus*, is distinct from the theoretical vocabulary, such as *electric field, temperature, or mass*. The former refer to directly observable entities, and can be verified by direct observations; the latter do not and can not. Some accounts of how these two languages are linked propose various kinds of intermediary translation statements and distinctions between theoretical and observation statements. One view is that theoretical statements are derived from observational statements, as in positivism and logical empiricism. This is the basis for a criterion of validity, in inductionist theory, or a criterion for demarcation between meaningful and meaningless statements. Thus the RV entails ‘objective’ or theory-free observation in science. A second view is that ‘observational statements are shaped by theoretical considerations without which they have no meaning’ (Callon 1995, p. 32), by which account observations are ‘theory-laden’. A third view denies in the first instance the implicit hierarchy between observational and theoretical statements in the first two views, by assuming that the different types of statements are more or less independent and simply testing predictions from theory or judging the explanatory successes of competing theories (Callon 1995, pp. 31-2).

For example, in the positivist RV, observations are taken to be (1) simple, direct perceptual experiences with the aid of no or very simple instruments, and (2) objective in the sense of being uninfluenced or free of theory. The RV regards the notion of being directly observable as ‘nonproblematic and generally understood’ (Suppe 1979, p. 46), in which those looking at the same objects ‘see the same things’ (Suppe 1979, p. 153). They *see the same things* because these direct observations are expressed in a shared language which is theory-neutral.

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10 This is also discussed in section 5.7a, above, and in Appendix B.4.
Critiques of this account of observation form part of the rebuttals of the RV, as mentioned already. For example, the fact of optical illusions conflicts with the notion that two observers looking at the same object and using the same observation language see the same thing, as discussed in almost any undergraduate text dealing with human perception. Neural or retinal activity is not the same as observing. Also, the observation-theory distinction is at least 'untenable' (Suppe 1979, p.153) if not refuted. Drawing on arguments by Achinstein and Putnam, Suppe (1979, pp. 80ff) concluded that the observation-theory distinction (1) fails to provide an empiricist methodology as sought by the RV; (2) has not been drawn successfully, nor can it be done plausibly in ordinary use of natural scientific languages; (3) would not be significant philosophically or revealing epistemically; (4) does not characterise ('capture what is distinctive' of) either the language of theories or observation reports. Further, the account of observation in the RV as being 'unproblematic' is inadequate, both because it fails to support the observation-theory distinction, and because it is less plausible than more detailed characterisations of observation. For example:

Achinstein (1968) maintains, correctly I think, that in the relevant scientific sense observation involves attending to something in a way which (1) is influenced by my concerns and knowledge [by which I decide which aspects of the object and how many to attend to], (2) does not require recognising what is observed [because I may need only to attend to certain aspects of the object, not the whole], (3) allows one to observe what is hidden from view [in the sense that a ranger observes a fire by seeing smoke], (4) may involve seeing an intermediary image [in the sense of seeing myself in the mirror], and (5) allows what I am observing to be described correctly in different ways [in the sense of describing what I observe in the sky as a speck or an airplane]. (Suppe, 1979, pp. 196-7)

Thus observation is not clearly separated from terms belonging to the paradigm or the world view (Weltanschauungen)\(^\text{11}\). Finally, a significant component of arguments for the theory-dependence of observation derives from the view that our language resources influence or determine our observing and our theorising. This issue is discussed in more detail below.

**Observation and language**

The second and perhaps more fundamental issue concerning observation is the view that language plays a fundamental role in observation. The general matter of language and science is addressed in the companion chapters on belief system and structure\(^\text{12}\), covering viewpoints ranging from simply the formal constructs of scientific language to the notion that language forms our knowledge of Nature. The debate concerning the latter viewpoint matter is of interest here. The later work of Ludwig Wittgenstein (1889-1951), particularly as adopted by Norwood Russell Hanson (1924-

\(^{11}\) See chapter 6 and Appendix B.1 on context.

\(^{12}\) For extended discussion, see Appendices B.2 and B.4.
1967), emphasised the role of language in determining perceptions (the 'concepts-influence-percepts' thesis):

Citing Wittgenstein extensively, Hanson produced a wealth of argument - psychological, historical and philosophical - to convince readers that we never just 'see' the world, passively absorbing impressions and then interpreting them, as the positivist sense-data theorist might lead one to believe. Observation, Hanson argued, is always an active process that is shaped by one's theoretical expectations, cultural assumptions, and linguistic background and attributes (Oldroyd 1989, p. 230).

This is consistent with several current metascientific viewpoints, such as constructivism or constructionism and Bhaskar's scientific realism (see Table B.5.1), and critiques of induction, as given above.

In traditional accounts, including the RV, language is viewed in science as a tool, and its relationship to observation as the means of inscribing and manipulating marks. Alternative views, however, are that the language resources available are constituents of observing and theorising, on some accounts by shaping or influencing and on others by actually determining.

Halliday (1990, pp. 10-11) has proposed a similar typology of three broad views. In the first view, the overall structure and content of the semantic system of the language is essentially unchanged; new objects, institutions and abstractions are constantly being created and being named, 'but naming new things (in this view) does not by itself perturb the semantic environment - hence if new grammatical forms arise in the course of technical development, they have been borrowed' (Halliday 1990, p. 10).

In the second view, language is continually evolving in response to changing material and non-material conditions in a culture:

The language thus optimises itself in relation to its environment; new forms will arise when called for - they do not need to be borrowed ...[T]his view would hold that language reflects reality through the intermediary of human cultures; hence in the long run the grammar changes in response to the patterns of cultural change, even if the process is a very gradual and indirect one. (Halliday 1990, p. 11)

The third view is that our language actively constitutes our perceptions of reality:

In this view language does not passively reflect reality; language actively creates reality. It is the grammar - but now in the sense of lexicogrammar, the grammar plus vocabulary, with no real distinction between the two - that shapes experience and transforms our perceptions into meanings. The categories and concepts of our material existence are not 'given' to us prior to their expression in language. Rather, they are constructed by language, at the intersection of the material with the symbolic. Grammar, in the sense of the syntax and vocabulary of a natural language, is thus a theory of human experience. It is also a principle of social action. In both these functions, or metafunctions, grammar creates the potential within which we act and enact our cultural being. This potential is at once both enabling and constraining: that is, grammar makes meaning possible and also sets limits on what can be meant. (Halliday 1990, p. 11)
This view, which Halliday endorses, draws on examples from various cultures demonstrating a match between their particular conceptual frameworks and associated linguistic features: ‘this cultural reality is actively constructed by regular and systematic features of the grammar of the languages concerned’ (Halliday 1990, p. 18).

Three criticisms of Halliday’s view will serve to illustrate the conflict between characterisations here. First, while the bulk of Halliday’s argument is a very plausible account for linguistic construction of social realities, such as the public discourses concerning pollution or resource usage, comparatively little attention is given to the more contentious question of an ontological reality. It does not seem as strong an argument for constructionism as for social and personal realities:

Language is not a superstructure on a base; it is a product of the conscious and the material impacting each on the other … Hence language has the power to shape our consciousness … [S]ince language evolves out of the impact between the material and the conscious modes of being, it follows that as material conditions change the forms given by language to consciousness also change. (Halliday 1990, p. 11)

This seems to allow for an ontology of an external, material reality, while arguing for our understanding of it being shaped by our language; to this extent it seems consistent with Bhaskar’s realism, for example.

Secondly, Halliday’s discussion of the linguistic forms that developed during the Scientific Revolution is not always clear as to whether the linguistic forms developed before, during or after new scientific developments. From some sort of Kantian idealism one could argue that the linguistic structures must precede the concepts, but from a non-idealist viewpoint it must surely be the case that the linguistic structures develop after, or at best alongside, new scientific developments (Wilson 1994).

Thirdly, Halliday does not explain the actual role of language in this ontological/epistemological ‘impact’.

This complex characterisation of science from a linguistic viewpoint is made nevertheless in terms of activities: from, essentially, reporting in Halliday’s first account, to representing and reporting in the second, to constructing, representing and reporting in the third. On the constructionist view, as proposed by Halliday, the activity of constructing reality is based on the available linguistic structures somehow ‘impacting’ on the material world. On Wilson’s critique, however, these constructions of reality occur before the linguistic structures themselves have been constructed. Many sophisticated post-positivist accounts reconcile these viewpoints; in Bhaskar’s scientific realism, for example, their is an external reality with characteristic structures, but our knowledge of it is constrained by being personally and socially constructed. Both of these accounts posit observation as a complex interaction of several activities intervening on the simple activity of sense perception.
5.7c. Explanation

A third type of activity often featured in characterisations of science is *explanation*. As with *experiment* and *observation*, *explanation* is used widely in non-scientific contexts:

*Explanation*:
to make plain or clear: render intelligible (*The Macquarie Dictionary*)

and in more specialised contexts:

The process or account by which something is made intelligible, where the account is called the *explanans*, and the thing, which may be a statement, event, state, process, law, theory, etc. is called the *explanandum*. (Bhaskar 1983d, p. 140).

In essence, this activity concerns the *communication of meaning*, and while both public and technical understandings of the term recognise the role of explaining in producing knowledge, scientific explanation is restricted by what this meaning can refer to. Again, it is subject to metascientific debate: what it means to explain depends on which theory of explanation one uses, but as elsewhere the main current positions are realist, empiricist and contextualist or relativist (Bhaskar 1983d; Sloman 1988; Bakker & Clark 1989; Gasper 1991; Salmon 1993). The public perception of, and response to, scientific explanation is significant in considering the role of science and scientists in general society, and points to a need to clarify these differences in interpretation of explanation.

A traditional account of explanation typically follows a progression from Aristotle’s four causes, to Hume’s critique of causation, the positivist response to Hume’s scepticism, Hempel’s covering-law model, and to relativistic or contextualistic accounts as in Scriven, the later Wittgenstein, feminist critiques, and others (Bakker & Clark 1989). Thus Aristotle claimed that we have understanding of the different kinds of things when we can answer four types of questions of the type *through what?* or often *why?* The answer to each can be thought of as *because*, hence they are known as Aristotle’s *four causes* (Tiles & Tiles 1993, p. 96). That is, in the Aristotelian scheme, to explain X is to answer one or more of these questions concerning X. However, because Aristotle valued the causes that referred to ends (*tele*, final causes) as the most important, being concerned with what is a ‘good’ outcome for X, this led to what was much later interpreted as a conflation of science and theology:

For philosophers in the seventeenth and eighteenth centuries, debate about what is ... good would inevitably lead to debates into which theology had to enter. (Tiles & Tiles 1993, pp. 97-8)

Hume, however, was sceptical of power or agency, and dismissed the notion of cause as merely our being accustomed to regularities in sequences of sense impressions, that is, as habits of mind (Tiles & Tiles 1993, p. 112). The response of positivists such as Mach was to reject explanation as scientific and allow only description and prediction.
Appendix B.5: Activity

This addressed Hume's scepticism of causality and excluded metaphysical, theological or anthropomorphic explanations from science. As part of the RV the rejection of scientific explanation was widely held for particularly the first half of the twentieth century.

The covering-law model of explanation

However, from the 1930s and especially in the 1960s and 1970s, the RV rejection of scientific explanation shifted to allow that a scientific explanation of a phenomenon is possible by showing how the phenomenon is subsumed or covered by a law of Nature (Salmon 1993, pp. 130-1). This is the deductive-nomological (D-N), covering-law or Popper-Hempel theory of explanation. It is deductivist, because a statement or conclusion is logically deduced from a set of initial conditions and a set of laws, generalisations or regularities:

Copper conducts electricity because {initial condition} copper is a metal and {covering law} metals conduct electricity.

Its deductive argument means that the explanandum has to follow from the explanans; this certainty is posited as a strength of the D-N model. Sometimes reference to a covering-law is implied only:

Copper conducts electricity because {initial condition} copper is a metal in which case it may be called a causal explanation.

There are problems with deductivist explanations. For example, like any logical deduction, the conclusion does not contain any more information than is given in the premises, and so this type of explanation is technically only a redescriptions. Secondly, any number of initial conditions can be made to entail an explanans, and so there is a need for some requirement of truth or confirmation of the explanans. Thirdly, either the deducibility or covering-law requirements can be largely satisfied without the other.

In some variants of the RV, the explanation is also an argument from a generalisation but is subsumed under statistical laws, where the argument is inductive. Given the explanans, the explanandum is inductively probable or expected rather than true or necessary. This is the inductive-statistical (I-S), inductive-probabilistic (I-P), statistical or probabilistic explanation. Probabilistic explanations are common in psychology and the social sciences. Hempel proposed two criteria for judging the adequacy of an explanation: that the explanation is (a) judged as relevant (meaning the explanation is implied in D-N examples or highly probably in I-S examples), and is (b) testable (van Fraassen 1991, p. 318).

The contextualist model of explanation

An alternative to D-N and I-S accounts is the contextualist explanation, a social exchange which has a similar structure to the D-N model but with broader parameters such as semantics (familiarity, plausibility and coherence) and pragmatics (relevance).
Thus an explanation occurs when one's puzzlement is resolved, and may require reference to matters already known. For example, van Fraassen (1991) has emphasised the pragmatic nature of explanation:

Scientific inference is inference to the best explanation. That does not rule at all for the supremacy of explanation among the virtues of theories. For we evaluate how good an explanation is given by how good a theory is used to give it, how close it fits to the empirical facts, how internally simple and coherent the explanation. There is a further evaluation in terms of a prior judgement of which kinds of factors are explanatorily relevant. If this further evaluation took precedence, overriding other considerations, explanation would be the peculiar virtue sought above all. But this is not so: instead, science schools our imagination so as to revise just those prior judgements of what satisfies and eliminates wonder. (van Fraassen 1991, p. 326)

Gutting (1984, p. 97) has set out two schemas for explanation, which appeal respectively to the reasoning process and the circumstance:

[T]here are two different ways of explaining beliefs. The first, which I'll call Type I explanation, makes essential reference to the reasoning processes that give rise to a belief ... Type I explanations have the following form:

(i) S believes p'.
(ii) S reasons in manner R and believes the results of his [sic] reasoning.
(iii) Given p', reasoning in manner R results in p.
(iv) Therefore, S believes p.

But, of course, there's another way of explaining beliefs: Type II explanations, which refer only to circumstances that do not involve reasoning processes. These have the general form:

(i) Anyone in circumstance C believes p.
(ii) S is in circumstance C.
(iii) Therefore, S believes p.

(C, of course, is a circumstance that does not involve S’s employing any reasoning processes). (Gutting 1984, p. 97)

By means of a hypothetical exchange between a sociologist advocating the strong program and philosopher opposing it, Gutting set out opposing concerns about the strong program's appeals to Type I and II explanations. Thus the philosopher identifies Type I explanations with the beliefs held by scientists and Type II with the strong program. The sociologist replies that the strong program in principle accommodates both, although sociologists have an interest in Type II explanations 'maybe because its those that undermine the philosophers' paradigm of rationality' (Gutting 1984, p. 98). Thus to return to the copper example, a contextualist explanation could take the form:

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13 Bloor (1976) has argued that all science is explained by a combination of epistemic and social factors, as in contextualist models of explanation. Given this, he is critical of the tendency to explain science and scientific successes by one set of criteria, such as rationality, and non-science and scientific failures by other criteria, such as sociological and psychological factors. He argues in the 'strong program' that explanations of science should be the same as explanations in science in that they are symmetrical: there should be the same type of explanation for true or false beliefs. (See the discussion of externalism and internalism in the companion chapter on context).
Copper conducts electricity because it satisfies accepted behaviours of metals subjected to a potential difference.

For Bhaskar (1983d), this model has difficulties demonstrating the necessary or sufficient conditions in historical examples; it may also lead to confusion instead of clarification.

**Realist models of explanation**

The third main alternative, modern realist explanations, seeks to include the insights of both deductivism - as a causal account - and contextualism - as a ‘socially produced (and fallible)’ account of phenomena (Bhaskar 1983d, p. 141). For scientific realists, explanations are approximately true to the extent of their empirical support, rather than empirically adequate as empiricists typically maintain (Boyd 1991, p. 372). In this account there are two kinds of explanation. Theoretical explanations describe the law-like behaviour, formulate possible explanations by retroduction, and empirically identify the responsible causal mechanism:

Electric current flows when electrons flow through a conductor. Electric current as measured by an ammeter flows through copper when a potential difference is applied. Copper is an electric conductor.

Practical (applied) explanations resolve a complex event or situation into its components, redescribe the components theoretically, formulate possible antecedents to the components by retroduction, and eliminate possible alternative causes.

This provides a contrast with non-scientific explanations used by the general public:

From this perspective, scientific explanations differ from lay explanations not so much in their form, as in their conceptual content, circumstances of production and (empirical, logical and contextual) controls. (Bhaskar 1983d, p. 142)

The more sophisticated characterisation of a realist account of explanation such as this informs discussion about differences between ‘scientific’ and ‘lay’ uses of the term.

**Teleological explanations**

Finally, as mentioned in Appendix B.2, one of the differences between Aristotelian and Classical sciences is the general rejection of final causes, that is, teleological explanations. Teleological explanations can include explanations of either function or purpose, since these two are often indistinguishable. Explanation in terms of purpose ‘are common in everyday life and law courts, but also in some of the social sciences and psychology’ (Sloman 1988, p. 300) and embryology. Apart from this, teleological explanations are generally not used in science, either because mental functions are not regarded as scientific, or because an explanation of an event by a tendency to that effect is not regarded as an explanation.
5.7d. Prediction

The fourth activity to be mentioned here is prediction, again a term used by both scientific and lay communities, to mean 'to foretell the future' (The Macquarie Dictionary). The notion of prediction in science is central to a number of metascientific claims of reliable knowledge (on which predictions can be based), and the utility of science (arising largely from its predictive ability):

Needless to say, the most impressive way of validating a scientific theory is to confirm its predictions ... (T)he persuasive power of a successful prediction arises from the fact that it could not have been deliberately contrived. (Ziman 1978, p. 31)

Ziman goes on to point out that this impressiveness is not logical, in that it does not matter logically whether a novel observation is made before or after a theory is formulated. It is, however, very persuasive psychologically.

As with other scientific activities, there are different accounts of prediction in the metascientific literature. Bhaskar (1983j) has identified four classical conceptions of the role of prediction within HPS but rejects these in favour of a fifth. Thus the positivist view is that prediction serves for the control of Nature. The instrumentalist view is that prediction and summary of phenomena arise from laws and theories, but understanding does not. The deductivist view is that prediction and explanation are symmetrical, and that explanation can become prediction. The inductivist and falsificationist view is that prediction is the test of a theory. Bhaskar holds that each of these views is untenable because it requires a closed system, which is 'not generally available'. That is, prediction can never be certain because we cannot in advance account for all variables in real systems. Instead, he posits a realist view:

Thus, laws and theories do not license deductively justified predictions in open systems, but rather enable the analysis and retrodiction of phenomena; and the chief aim of theoretical science becomes once more understanding rather than controlling Nature. (Bhaskar 1983j, pp. 336-7)

Gallon's (1995) overview of STS accounts of scientific development incorporate prediction into various schemas: making verifiable predictions is central in some views of science-as-rational-knowledge; and prediction, manipulation and control are emphasised where science is characterised as sociocultural practice.
5.8 Mathematical activity in science

A significant aspect of scientific activity is mathematical, as both the direct and indirect representation of Nature by mathematical processes. We will mention four indicators of this here: (a) the historical interplay of mathematics and science; the mathematics of (b) algebra and (c) infinitesimals as powerful tools of analysis and description; and (d) the marked developments of mathematics in twentieth century science, especially in physics.

5.8a The historical use of mathematical processes in science

Mathematical processes have been used in science from antiquity, notably by Plato, the Pythagoreans, Archimedes, Euclid and Ptolemy. The role of mathematics in science shifted particularly in the Scientific Revolution, as indicated in summary statement 72 (Needham 1969). Schuster has characterised the Scientific Revolution by conceptual breakthroughs, two of which rest on developments in mathematics:

\[ \ldots \text{Galileo and Newton laid the foundations for classical mathematical physics} \]
\[ \ldots \text{and Descartes, Pierre Fermat, Newton and Gottfried Wilhelm Leibniz created} \]
\[ \text{the first modern fields of mathematics, coordinate geometry and differential and} \]
\[ \text{integral calculus (Schuster 1990, p. 217).} \]

Further, mathematics became part of the conceptual and methodological resources in the emerging interest in how the new science actually worked, that is, in seeking more reliable and precise methods for interrogating the cosmos. The revival of interest in Greek geometrical analysis was associated with the ‘broader and very fluid contemporary interest in “method” as a tool of discovery, proof and teaching, on the part of humanists and Aristotelians alike’ (Schuster 1990, p. 233).

The precision of mathematical techniques also lent itself to characterisations of a difference between mediaeval scholastic science and the classical science that emerged in the Scientific Revolution, notably as a change from qualitative to quantitative approaches:

It is a current conception that one of the most characteristic differences between scholastic and more recent physics is that the former was of an exclusively qualitative nature, whereas in the latter the quantitative point of view predominates. This characterisation is undoubtedly correct when it is intended to convey that in peripatetic science the concept of quality took a much more important place than in classical science, in which every effort is made to reduce qualitative to quantitative differences; it would, however, be less correct, at all events with respect to the fourteenth century, if it implied that in Scholasticism there was no tendency to treat qualities quantitatively, while fully preserving their independent meaning. (Dijksterhuis 1986, p. 188)

The significant mathematical development at this time is attributed usually to Galileo Galilei. Galileo revived the experimental basis of Aristotle, but proposed a different cosmology to Aristotle’s, which (as with Plato’s) could be represented mathematically:
In Aristotle's physics, motion was regarded as a quality: a body would be moving or stationary according to whether it possessed the quality of motion. But it was not possible to treat such an Aristotelian property satisfactorily in terms of numbers, and hence examine the phenomena of motion in more than a general manner. By contrast, Galileo's falling bodies were, so to speak, 'mathematical' entities, moving in 'mathematical' space. All their attributes (such as colour, smell, weight, etc) were disregarded (for the purpose of the experiment on falling bodies), and attention was focussed solely on position and time. So in a sense Galileo was no longer dealing with real bodies moving in real space, but with 'mathematical fictions'. (Oldroyd 1989, p. 58)

However, Galileo refrained from representing the cosmos in terms of mathematical models without recourse to experiment, as a strict neo-Platonist would be content to do. John Heilbron (1983b) has made such a distinction between Galileo and his Mediaeval predecessors in terms of these beliefs:

But these anticipators [such as Nicole Oresme (c1320-1382) and Domingo de Soto (c1494-1560)] do not appear to have shared Galileo's approach: they investigated laws of motion as mathematical possibilities, he as testable descriptions of Nature. (Heilbron 1983b, p. 229)

The interplay between mathematics and science was strengthened by Rene Descartes, whose Cartesian system justified a mathematical approach that is identified down to the present day (Singer 1959; Dijksterhuis 1986). In idealist or constructivist interpretations such as Descartes and Kant the products of mathematics and science result from mental activity:

...Kepler and Galileo were deeply convinced that ... the structure of the world was essentially mathematical in character and a natural harmony existed between the universe and the mathematical thought of the human mind.

Now the standpoint taken by Descartes cannot be better described than by saying that by carrying this conception to its extreme he virtually identified mathematics and natural science. Natural science is mathematical in character not only in the wider sense that mathematics ministers to it ... but also in the much stricter sense that the human mind produces the knowledge of nature by its own efforts in the same way as it does mathematics. (Dijksterhuis 1986, p. 404)

The most comprehensive and successful expression of this interplay between mathematics and science of that time is usually taken as the work of Isaac Newton. From Newton's work, mathematics, including the mathematics of infinitesimals, became a widely used tool for analysing physical change:

Newton (1642-1727) mathematised force, analysing the gravitational attraction between gross bodies into contributions from their infinitesimal elements (Principia, 1687)...

The subjects mathematised during or before the 17th century - astronomy, geometrical optics, hydrostatics (hydrodynamics), and mechanics - were not considered 'physics' by contemporaries. They were practical subjects, belonging to applied mathematics. In the 18th century the calculus was applied to these subjects, which were greatly expanded, and also to branches of optics.

Electricity, magnetism, heat and physical optics belonged during the 18th century to experimental physics, an empirical, non-mathematical discipline before about 1770. Two factors contributed to the mathematisation of experimental physics. Improvements in scientific instruments permitted exact
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measurement of physical quantities. From these algebraic laws were derivable, but neither measurements nor empirical laws can be called mathematical physics. Exact measurements, however, encouraged the establishment of theories to account for them. By this time physicists were less reluctant to ascribe distant forces to imponderable fluids. (Feldman 1983, pp. 250-1)

Thus the history of science is characterised partly by the development and use of mathematical activities, allowing greater precision, the measurement of phenomena previously not subject to manipulation, and ultimately to shifts in scientific theorising, concepts and knowledge because of mathematical activity. Two particular examples - algebra and calculus - and the accelerating use of mathematics in twentieth century science are taken up further, below.

5.8b Algebra

A particular example of mathematical activity in science is the use of algebra, interpreted here as the mathematical manipulation of symbols. Dijksterhuis (1986, p. 188) has noted that the term algebra 'in the sense of a system of letters symbolising all existing magnitudes, no matter whether they are constants or variables, known or unknown quantities' was not used until the seventeenth century. Prior to about 1800, algebra was taken to concern numbers and number systems, such as the solution of numerical or algebraic equations. Some historical indicators include Aristotle's use of letters to represent variable magnitudes, and the adoption in western Europe from c.1500 of standard algebraic symbolism and techniques, from the Arabic number system which in turn had been adopted from the Indian or Hindu number system (Dijksterhuis 1986, pp. 109-115). In the fourteenth century, a branch of Scholasticism called Calculationes (the 'Calculators'), used symbols as a means of language shorthand, then to denote magnitudes of concepts such as motion, and even to concepts such as sin and grace which are not regarded now as being appropriate for quantification. In the sixteenth and seventeenth centuries particularly, algebra flourished:

However, the seventeenth and eighteenth centuries were to witness a transformation of algebra and the flowering of algebraic analysis. Pierre de Fermat (1601-65) and René Descartes (1596-1650) independently showed how the algebraic notation of François Viète (1540-1603) could be applied to the solution of geometrical problems. Their new analytical geometry was able to generalise and extend the results of ancient Greek geometers ... (Kitcher 1990, p. 679)

Developments in the nineteenth century included theories of groups, fields, higher order equations and vectors. In the twentieth century algebraic structures have tended to be regarded 'from an abstract and axiomatic point of view ... as a study of abstract structures such as groups, rings, fields, lattices, and vector spaces' (Johnson 1983, p. 11).
5.8c Mathematics of variability

The other mathematical activity to be considered here is the mathematics of variability, in the general sense of techniques for representing continuous change. In antiquity, Eudoxus (c400-347BC) proposed a method of exhaustion, which was subsequently developed by Archimedes (c287-212BC) to determine the areas of curvilinear figures (Dauben 1983, p. 14), but the mature development of the mathematics of variability was the period leading into and including the Scientific Revolution.

The ability to represent variability is fundamental to conceptualising motion, among other things, and the first significant development in this respect was the graphical representation introduced by Nicole Oresme (c1320-82). In mechanics, for example, it far easier to grasp intuitively the slope of a tangent of the curve, when distance $s$ is graphed against time $t$, than the limit of the quotient $ds/dt$ as the numerator and denominator approach zero. Since both of these represent instantaneous velocity, it is clear, then, that the development of graphical representation greatly assisted thinking in this field before the notion of a derivative matured. This contributed to the reassessment of ontological beliefs, particularly the long-held belief in the perfection of circles and spheres, and that the cosmos is so constructed as to exhibit invariant spherical and circular forms:

The graphical representation thus created the possibility of illustrating the concept of instantaneous velocity geometrically and of gaining, on the strength of this, an insight into kinematic phenomena that was as yet unattainable by analytical methods. This was of great importance especially at a time when algebraic symbolism, which was indispensable to the evolution of the calculus, was still in its infancy.

The gradual introduction of what may be called the mathematics of variability in the period beginning with Oresme and ending provisionally with Newton and Leibniz implied the pursuit of a direction leading away inevitably from the sphere of ancient mathematics. It was a first symptom, showing that the guidance of antiquity, which had hitherto shielded mathematical thought from many dangers, was being gradually abandoned. To the rigorous mathematics of the ancients, which was born of the spirit of Platonic philosophy and in which true reality was characterised by invariability, any scientific treatment of variability as such had been inconceivable. Once it had assimilated the mathematical knowledge of Antiquity, one of the great tasks before the Renaissance mind was to break the barriers it had erected against the growth of mathematics, and thus not only to raise this branch of science itself to an unthought-of height but also to make it subservient to natural science. (Dijksterhuis 1986, p. 263)

These developments served to prepare an even more significant mathematical development, the calculus of Newton and Leibniz. The calculus illustrates a recurrent issue for interpretation in papers such as the present thesis, which is the role of individual characteristics in the whole. There is no doubt that the calculus, as a set of mathematical procedures, is a most useful mathematical tool for description and analysis. But there is
also a sense in which the calculus is more than just a tool to help 'do' science and actually is constitutive of the science itself:

... Building on the work of Descartes, Fermat and other mathematicians, Isaac Newton (1642-1727) and Gottfried Leibniz (1646-1716) independently formulated the principles of the differential and integral calculus. Using the new calculus, Newton and Leibniz computed the values of the areas under many curves, found the length of arcs, identified radii of curvature, constructed tangents and normals and solved problems about the motions of ideal particles. The Marquis Guillaume de l'Hôpital (1661-1701), the author of the first textbook on the Leibnizian calculus, claimed that the new methods enabled mathematics to solve problems which 'nobody previously had dared to attempt.' (Kitcher 1990, p. 679)

Thus while electricity, magnetism, heat and physical optics were studied in an empirical and non-mathematical way prior to about 1770, use of the calculus enabled accurate descriptions of physical variability. From its use were developed quantitative laws describing fluids, electricity and magnetism by about 1800 and optics and electromagnetism in the early 1800s (Feldman 1983, p. 251). Kitcher's remarks clearly characterise science partly by the method of calculus, although they are ambiguous concerning the interpretive question of whether he considered the calculus was a tool in this development or an integral part of the development itself. Redner (1987), however, has argued explicitly that in the twentieth century, mathematical processes fundamentally characterise scientific activity, as we shall see in section 5.8d, below.

5.8d Mathematics in twentieth century physics

In the twentieth century, mathematics has had a remarkably influential role in science, especially physics. That is, although mathematical processes have been used to represent the cosmos scientifically especially since Galileo, Descartes and Newton, mathematical activity characterises twentieth century science even more profoundly. Twentieth century physics, notably quantum and relativity theories, has undergone fundamental changes and now entails strikingly counter-intuitive views of the cosmos\textsuperscript{14}. It is a central theme in most accounts that twentieth century physics is characterised by a fundamental interplay with complex mathematics that renders non-mathematical understandings at best only approximations, and conceptually difficult approximations at that:

\begin{quote}
Some of the new concepts [of physics] are fully meaningful only in mathematical language. (Davies & Gribbin 1991, p. 3)
\end{quote}

In the overthrow of the old world view - a paradigm shift that is dramatically transforming our understanding of reality - the chief casualty is common sense.

\textsuperscript{14} There is also an argument that Newtonian science is counter-intuitive, when compared to Aristotelian science, for example; that Newtonian science is commonsensical to those of us who have received a science, or at least a physics, education. Nonetheless, the counter-intuitive nature of twentieth century physics arises largely from its mathematical character.
Whereas in the Newtonian picture of reality human senses and intuition proved a good guide, in the abstract wonderland of the new physics it seems that only advanced mathematics can help us to make sense of nature. (Davies & Gribbin 1991, p. 11)

Books of this type are an excellent first step in demystifying the new physics. However their very existence points to the developments made with mathematics. It is no reflection on the clarity of writing that Hawking’s (1988) *A Brief History of Time* is described on the cover as ‘the international number one best seller’ yet has been jokingly referred to in the media as ‘the world’s least-read coffee-table book’. The material dealt with in texts such as these - quantum theory, relativity, singularities, the exclusion principle, imaginary time, quarks, string theory, chaos theory, and so forth - are just as the authors describe: sophisticated mathematical representations of the cosmos, that cannot be understood without the mathematics. They can be described in general terms without the mathematics, but the general descriptions have to be accepted on faith, and with so many complex and counter-intuitive concepts, that is indeed a problem for the public understanding of science. The mathematical representation of reality is central to characterising twentieth century physics and many other sciences also.

A different perspective on the mathematisation of twentieth century science is given by Redner (1987), who argues that twentieth-century World science is characterised by *technification*, usually accompanied by *formalisation, abstraction* and *problem-solving*:

These thematic categories are usually linked by a more general tendency towards what Whitley (1977), following Georgescu-Roegen, has called ‘arithmomorphism’ or the ‘arithmetic ideal’. The introduction of mathematical techniques into science can take place for many reasons. These can be technical and practical - to facilitate calculation, for example, and to make certain kinds of problems solvable; or formal - to place the science on a more rigorous and so scientific footing, for example, by introducing quantification and exactitude in definitions, relations and ‘laws’; or institutional - to establish criteria of professional expertise and technical competence, for instance; or philosophical - to permit a theoretical reduction of the objects of the science to those of a more general science, and eventually of all sciences to physics. But no matter why such techniques are included, their introduction will almost inevitably set up a tendency towards formalisation, abstraction and problem-solving. Formalisation occurs because once mathematical techniques operate to quantify relations and ‘laws’ there will be an irresistible intellectual pull to bring them together as a systematic and fully formal theory, which in extreme cases will be ‘closed’ and even axiomatised. Abstraction occurs because a mathematical description governing a few exact parameters constitutes an abstraction from reality; it is only applied to an ideal or abstract object selected from the multiplicity of actual objects and their properties. And finally, a science operating with mathematical formulae will invariably couch all questions in the form of exact problems for which there are presumed to be specific, if not unique, solutions, like those for a set of solvable equations. A mathematical, ‘closed’ and axiomatic science operating on highly abstract objects to solve intellectually constructed problems will almost always need to be finalised as well, since there will no longer be any

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15 See also Davies (1980), Hawking (1988) and Davies (1992)
'internal' direction for further research, the guidance of which will have come from outside ends. (Redner 1987, p. 71)

Each of Redner's characteristics of twentieth century World science - *formalisation*, abstraction and problem-solving - is in turn strongly characterised by mathematical processes. More than this, Redner's critique is that the increasingly mathematical characteristic of twentieth century (World) science establishes particular kinds of questions to be solved, which in turn lead to particular kinds of answers. Redner is less clear about the extent to which his notion of World science applies to all sciences, but to the extent his argument applies it identifies an increasingly fundamental character of mathematical activity in science. The outcomes of mathematisation Redner describes fit exactly the outcomes of, for example, Hawking (1988), who argued the apparent tendency of the fundamental physics theories - that is, theories that are characteristically mathematical - to converge. He speculated that such a convergence could in principle answer how and why the universe started and runs as it does, interpreted in his now well-known concluding paragraph:

However, if we do discover a complete [unified] theory [of physics], it should in time be understandable in broad principle by everyone, not just a few scientists. Then we shall all, philosophers, scientists, and just ordinary people, be able to take part in the discussion of the question of why it is that we and the universe exist. If we find the answer to that, it would be the ultimate triumph of reason - for then we would know the mind of God. (Hawking 1988, p. 185)
5.9 Debate over discovery and justification

We have noted above an enduring historical theme of a twofold pathway of reasoning, identified in the inductivism of Francis Bacon, for example, and in the hypothetico-deductivism that displaced it. Part of that discussion concerned the distinction between two contexts characterised respectively by the activities discovery and justification. As broadly understood now, this distinction was conceived by John Herschel (1830). According to Herschel, the set of activities called discovery included the selection of relevant criteria from complex phenomena (a process for which there are no rules), and from these the successive formulation of higher and higher principles, first as law-like regularities and eventually as theories, either by induction or the formulation of hypotheses. From there, in the context of the set of activities called justification, he reasserted deductive reasoning as the path for prediction from these laws and theories.

Herschel's distinction can be viewed as the basis for a number of accounts that either acknowledge discovery but dismiss it as beyond the province of metascientific understanding, as in positivism, or focus on the metascientific neglect of discovery as a significant gap in developing an understanding of what science is and how it works. In the first half of the twentieth century particularly, the RV strongly characterised science by the activities summarised as justification, and not discovery:

Much of traditional epistemology is devoted to the study of the justification or, more generally, the evaluation of the beliefs we have on the basis of some given body of evidence. Recently, belief revision has claimed its place as a further chapter of epistemology. In contrast, relatively little attention has been devoted to the epistemology of knowledge acquisition. One (usually tacit) reason for this neglect is the belief that the most important types of knowledge acquisition, e.g. the discovery of a new scientific theory, are not subject to rules, and hence cannot be studied logically or epistemologically. (Hintikka 1992, p. 241)

The second factor, the rejection of the activities of discovery, is of particular interest here. This argument contributed to the positivists' rejection of activities that were not demonstrably rational. As a tenet of the RV, it remains current where derivatives of that view are still influential, but is disputed by characterisations that contributed to, and followed, the decline of the RV. It represents a touchstone for characterisations of scientific activity, as indicated in the following discussion.

The dismissal of a context of discovery is usually attributed to Hans Reichenbach (1891-1953):

The history of logical positivism on the discovery issue is also complex ... The official, logical positivist position on discovery is usually attributed to Hans Reichenbach, who, in Experience and Prediction (1938) distinguished 'context of discovery' from 'context of justification' and supposedly ruled context of discovery out of bounds to epistemology. A careful reading of that work reveals that Reichenbach's distinction had a different purpose. Indeed, Reichenbach himself believed in the existence of a sort of inductive-probabilistic logic of
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discovery, or rather, a logic of discoverability. It was primarily in Reichenbach’s and other positivists’ later writings that the ‘two context’ distinction became an invidious one. Ironically, at the very time these writers banished discovery as a legitimate methodological topic, some of them were contributing to the development of statistical inference and data reduction methods, such as factor analysis, which amounted to logics of discovery.

The later positivists came to focus more and more on the logical structure of the final products of research - theories, laws, explanations and empirical testing. Having stripped the process of research of all interesting cognitive-epistemic features, they assigned this topic to psychologists and historians! (Nickles 1990, p. 158)

Despite such criticism, it should be noted that the distinction between discovery and justification became more marked, not so much because of concern over weaknesses of the former, but because of the strengths perceived in assuring truth through the latter:

One of the consequences of the Reichenbach doctrine is that it is held that, whatever the origin of an idea, its truth can be determined independently of it. This is one of the main themes in Popper’s Poverty of Historicism, when he takes great exception to the relationalism of Mannheim and the sociology of knowledge. The veracity of a theory is not justified by changing political and cultural grounds. Hence the context of justification is apolitical. (Brannigan 1981, p. 42, emphases in original)

The position that science is only concerned with that which is logically demonstrable is central to the debates on the externalist/internalist distinction, discussed in the companion chapter on context and Appendix B.1, and in the section below. Alternative views, that discovery is not merely acknowledged but is significant to scientific activity, have become more influential with the declining influence of the positivist RV.

**The distorting effect of rejecting discovery as a characteristic activity**

There are several implications of the discovery/justification debate for the characterisation of science by activity. First is the criticism that omitting discovery distorts descriptions or explications of science. An eloquent, if stylistically dated, account of scientific activity which puts this view is Singer (1959). This view is quoted at some length not only because it puts a plausible account of scientific activity, but subsumes Oldroyd’s (1989) account of hypothetico-deductivism and roles in science for both justification and discovery. Singer in fact uses the omission of discovery as the criterion for judging Francis Bacon’s account of scientific activity as fundamentally limited:

The scientific man [sic] in the prosecution of his art of discovery has to practise three distinguishable mental processes. These may be considered as firstly, the choosing of his facts; secondly, the formation of an hypothesis that links them together; and thirdly, the testing of the truth or falsehood of the hypothesis. When this hypothesis answers numerous and/or stringent tests, he has made what is usually called a ‘scientific discovery’. It is doubtless true that the three processes of choosing facts, drawing an hypothesis or conclusion, and testing the conclusion, are often confused in his own thinking by the man of science. Often, too, his demonstration of his discovery, that is the testing of his hypothesis, helps him, more or less unconsciously, to new acts of judgement, these to a new selection of facts, and so on in endless complexity. But
essentially the three processes are distinct, and one might be largely developed while the others were in a state of relative arrest.

In this matter scientific articles, and especially scientific text-books, habitually give a false impression. These scientific works are composed to demonstrate the truth of certain views. In doing so they must needs obscure the process by which the investigator reached those views. That process consists, in effect, of a series of improvised judgements, or 'working hypotheses', interspersed with imperfect and merely provisional demonstrations. Many hypotheses and many demonstrations have had to be discarded when submitted to a further process of testing. Thus a scientific article or book which tells nothing of these side issues, blind alleys, and false starts tends, in some sort, to conceal the tracks of the investigator. For this reason, among others, science cannot be learned from books, but only by contact with phenomena.

The distinction between the process of discovery and demonstration of discovery was constantly missed during the Middle Ages. On this point, in which our thought is separated from that of the men of those times, Bacon remained in darkness. He succeeded, indeed, in emphasising the importance of the operation of collection of facts. He failed to perceive how deeply the act of judgement must be in the effective collection of facts. (Singer 1959, pp. 265-6)

That is, discovery is a distinct process (or collection of processes) which is systematically omitted from scientific accounts (including textbooks) because those accounts seek to show only the rationality of the reconstructed argument. Note that Singer makes a distinction between discovery as a process, which includes the activity of judgement, and scientific discovery as a product. Choosing facts, the first of Singer's three processes, presumably includes identifying and collecting them and other subtly different labels for associated activities, but begs the question of the role of theory in this process. As we have noted, many characterisations of science argue that the judgement that only particular 'facts' are useful presupposes a commitment to a particular theory or hypothesis; the present thesis adds beliefs and assumptions (belief system) as influencing the judgement of which data are relevant and useful.

Psychological and social models of discovery

Second is the question, what is this process of discovery, and various answers have been proposed. Brannigan (1981, pp. 13ff) has argued that there are two broad types of accounts of discovery: psychological and social.

Discovery as a psychological activity

Psychological accounts are so-called because each is a 'mentalistic' explanation, whether proposing genius, gestalt shift, recognition of anomalies or insight as the controlling variable:

[All these accounts offer explanations of the occurrence of discoveries by showing how, as a result of interaction with the environment, new ideas get into the researcher's head. Hence these accounts are all reductionistic. That is, they reduce the problem of historical discoveries to the psychological level. (Brannigan 1981, p. 33)
This mentalistic or psychological characteristic is evident in many accounts. For example, for Hanson, discovery is a different Gestalt or interpretation of perceptions, and its logic involves the reasons the scientist has for discriminating between different hypotheses. While this view accepts that some induction follows the recognition of an anomaly, its rejects simple enumerative induction. Kuhn has provided an account both of how individuals make discoveries and of how communities accept or reject them. For Kuhn, discoveries also start with the recognition of anomalies, but it is necessary also for the individual to recognise the significance of the anomaly, and for there to be adequate development of concepts and instruments. For Koestler, unlike Hanson and Kuhn, gestalts may be present but are not necessary; the distinguishing characteristic of any creation, inspiration or discovery, in science and in other contexts, is *bisociation* - 'the synthesis of a single idea with two apparently inconsistent contexts' (Brannigan 1981, p. 27). Thus, whether in science, literature or comedy, bisociation produces a cognitive tension, as in the well known example of Archimedes in the bath:

The change in the water level produced by stepping into the gymnasium bath was certainly something with which any experienced bather must have been familiar. However, Archimedes bisociated his observation of the change in water level with the question of the proportion of gold in Hiero’s crown. In other words, the commonplace displacement of bathwater became thematically important for the solution of a problem in another context. However, the inadvertent solution to the problem in the context of bathing constituted a surprise, a disruption of the mundane course of bathing. This accounts for the classical reports of Archimedes’ distraction and exuberance. (Brannigan 1981, p. 28)

Other examples given by Koestler include Gutenberg, who bisociated the action of the wine press with imprinting an image, Darwin’s bisociation of the immense diversity of species with Malthus’ notion of economic struggle, and Kepler’s bisociation of physical laws, which could account for elliptical orbits, with astronomy, which had used the metaphysical principle of the perfection of circles as the explanatory principle.

An example of such an account of discovery is the work by Charles Pierce (1839-1914) to produce a ‘logic of discovery’. He began with the criticisms of induction, and accounts that rely on some sort of induction. Two of these failings, as we have seen, are the failure to account for (1) how a hypothesis is made or constructed, and (2) how a decision is made to test some of the possible hypotheses and not others. Pierce argued that a logical account could be given of how one determines a hypothesis rationally:

Throughout his philosophical work, Pierce was greatly interested in logic, and it was, therefore, within this general framework of interest that he sought to construct a ‘logic of discovery’. In 1878, for example, he sought to clarify the distinctions between deduction, induction, and the process of hypothesis formulation, by means of the following simple examples:

(i) **Deduction:**
   Rule - All the beans from this bag are white.
   Case - These beans are from this bag.
   Therefore
Result - These beans are white.

(ii) *Induction*:
- Case - These beans are from this bag.
- Result - These beans are white.
- Therefore
  - Rule - All the beans from this bag are white.

(iii) *Hypothesis*:
- Rule - All the beans from this bag are white.
- Result - These beans are white.
- Therefore
  - Case - These beans are from this bag.

... The term that Pierce coined for the process which occurs when a hypothesis is formulated, in order to explain some puzzling phenomenon, was *abduction*. This may be represented by the following simple schema:

The surprising fact, C, is observed;
But if A were true, C would be a matter of course;
Hence, there is reason to suspect that A is true.

(Oldroyd 1989, pp. 184-5)

The process of *abduction* is similar to the notion of *retroduction* in Hanson (1958) and Bhaskar (1989): arguing ‘backwards’ from what is known or observed.

Pierce’s argument is part of the *pragmatist* tradition of thinking that held that the truth or meaning of an idea is given in its practical outcomes, also seen in the work of William James (1842-1910) and John Dewey (1859-1952). The proposal of a process of abduction is made therefore to address different concerns, which the present thesis identifies as purposes:

The logic of abduction thus investigates the norms employed in deciding whether a hypothesis is worth testing at a given stage of inquiry, and the norms influencing how we should retain the key insights of rejected theories in formulating their successors. (Hookway 1992a, p. 8)

In Pierce’s account, logic is concerned not with how we think, but how we ought to think, and he makes a connection between constructing hypotheses (abduction), the practical consequences of the hypothesis (pragmatism), and ethical or moral considerations:

So hypotheses should be formulated that could explain phenomena satisfactorily, were capable of experimental testing (a point with which the positivists would have agreed), and which could be investigated as economically as possible. Here questions of both mental economy (as in the employment of Ockham’s razor) and economy in terms of materials, time and other costs were relevant. Evidently, Pierce was giving sanction to the significance of socio-economic factors in the very cognitive structure of scientific knowledge, a position which the positivists such as Mach would have found quite unacceptable. (Oldroyd 1989, pp. 184-5)

This account provides a mechanism for judging, after the formation of the hypothesis, the range of factors that contributed to its formation.

Reactions to Pierce’s account illustrate some of the tensions of making the case for discovery as a scientific activity. Oldroyd, in the context of his historical theme of hypothetico-deductivism, finds no sustainable logic of discovery in Pierce’s argument,
only reasons why one argument might be preferred to others, because it 'still seemed to require flashes of insight, wit, genius, or whatever' (Oldroyd 1989, p. 187). Critics of abduction object that it is not true in the same sense as the deductive argument. Pierce’s pragmatism was directly opposed by Moore and Russell, for example, who ‘were scandalised by what they took to be a crass identification of truth and utility’ (Haack 1992, p. 354). The rebuttal of this criticism is that pragmatic truth is not equated with trivial, short-term utilities or expediencies, but with the long-term utility:

Fallible and imperfect as scientific inquiry is, however, if this vast co-operative enterprise were to continue long enough - Pierce is aware there is no guarantee that it will - eventually a final, stable opinion would be reached. (Haack 1992, p. 353)

This does not, of course, make a watertight account of discovery in science, but it does show how such an activity can be construed by alternative characterisations of scientific activity generally and of the nature of truth in science. In terms of activity, the example of Pierce retains empiricist characteristics, but includes the combination of deduction, induction and abduction in a longer-term context and applying to a different criterion of truth.

An alternative psychological account of the activity discovery is given by theories of knowledge-seeking by questioning (Hintikka 1992, pp. 241ff). Hintikka has proposed an interrogative model of inquiry, something like Socratic questioning, that can apply to scientific and other inquiries such as legal procedures. In its simplest form it involves an inquirer (such as a scientist, or a group or community of scientists) and the source of information, the oracle. An oracle can be a person, as in a ‘witness in a court of law or a patient in a diagnostic interview, but it can also be Nature as a target of observations and experiments’ (Hintikka 1992, p. 242). At each stage the inquirer can make either a logical inference or interrogate the oracle. Among Hintikka’s conclusions from this activity, are:

(a) there can be a rational (logical) theory of discovery, as well as logical theories of justification or evaluation, but that normally there are no mechanical (recursive) rules for discovery; (b) the reliability of oracles can be judged, and therefore the process can give insights into ‘the self-correcting character of knowledge-seeking methods’ (Hintikka 1992, p. 242); (c) an inquiry can serve to answer a question rather than prove a particular conclusion; (d) differences between types of inquiry can be characterised; (e) the nature of scientific inquiry can be clarified, notably by rejecting the belief that empirical scientific inquiry is atomistic; (f) the nature of discovery can be clarified; and (g) differences between kinds of knowledge can be characterised. The notion of an oracle implies that an assumption is made already about who ‘knows’ or might ‘know’.

**Discovery as a social activity**

For Brannigan (1981, p. 70), the naturalistic question of what causes a discovery is less productive than how they are identified as discoveries. He accepts insights from
psychological accounts, such as Gestalt shift or perception of anomaly, and the claim that inferences of that type are necessary. However, he judges them as a group to be insufficient in principle to account for discovery because all inferences of that type suffer the same limitation, that none is sufficient to distinguish discovery from mere learning. They provide no explanation for the uniqueness of the discovery: the original discoverer and the school student alike experience the Gestalt or flash of insight. Part of the problem, in Brannigan’s view, is that scientific discoveries are discoveries by definition - we are interested in them because they are recognised discoveries. Therefore they are post hoc explanations. If we seek a mentalistic explanation, its efficacy is assured since we are explaining a successful activity. The converse is not true generally: other sorts of explanations are given of non-discoveries - what are subsequently regarded as mistaken thinking. Thus psychological or mentalistic accounts of ‘discoveries’ like the phlogiston theory or the Piltdown Man, whether they appeal to Gestalt shifts or perceptions of anomalies, are inadequate: they fail to discriminate between scientific discoveries and either learning or errors.

In answer to this critique, Brannigan suggests a different notion of discovery in science:

[F]or Kuhn, discoveries are theoretical achievements which entail by definition a reflective reconstruction of experience. Excluded by fiat are simple factual discoveries. Hence the appearance of new elements would be simple novelties - which do not produce ‘discoveries’ - for discoveries are by definition theoretical breakthroughs and anomalies are those types of novelties which in the guise of explaining discoveries, only define them. (Brannigan 1981, p. 37; emphases in original).

It is reasonable to argue that scientific discoveries are marked by a change in theory, and if so, then aside from mental activity like insight there must be mental activity like theorising, and other activities such as explanation and defence of the theorising to the scientific community so that it is agreed to be a discovery. Following this argument, and consistent with his analysis of scientific ‘discoveries’ and ‘non-discoveries’, Brannigan proposed four criteria by which the conditions of discoveries and failures of candidates for discovery are typically understood. These criteria are essentially social rather than psychological. They are that an announcement or achievement is accorded the status of a discovery when it is (a) judged to be a ‘substantively relevant possibility’; (b) arises as part of ‘motivated scientific investigations or schemes of research’ - even so-called accidental discoveries, while temporarily inadvertent, arise precisely because they occur within specific and planned research activities; (c) judged to be ‘convincingly true or valid’ by scientific peers; and (d) judged by those peers to be unique, and therefore unprecedented (Brannigan 1981, p. 77).

Unlike Mannheim but following Barnes and Bloor, Brannigan argues that discovery is methodologically relativistic, meaning scientific discovery is subject to the
same scrutiny as any discovery. It holds that all knowledge, valid or invalid, is determined or constructed, unlike the assumption by many earlier sociologists that scientific knowledge is objective and other knowledges are socially determined. Therefore Brannigan’s account does not give scientific activity any special status that protects it from analysis. To do so, says Brannigan, undermines the credibility of scientific knowledge. However, he argues that discovery is not ontologically relativistic, meaning scientific discoveries do not arise in just any social context, but arise only as part of certain activities and within certain contexts. This is important, given that in recent metascience there is no agreed account of discovery, and views range from strongly internalist (allowing a psychology but no logic of discovery) to strongly relativistic (allowing that discovery in science is no different from any discovery). Accounts such as Brannigan’s attempt to address the criticisms from both camps, allowing the construction of knowledge (construction rather than discovery) while recognising that in science this is epistemologically special because of the context and other factors. This is consistent with views such as Bhaskar’s scientific realism, and with the present thesis, which extends Brannigan’s special conditions. That is, the construction (discovery) of scientific knowledge is epistemologically special because it takes place in conjunction with particular purposes, belief systems, (other) activities, contexts, knowledges and structures.
5.10 Activity as more than method and methodology: internalist and externalist perspectives on scientific activity

This final section addresses broader characterisations of scientific activity than just experimental and other activities most typically considered to characterise science. First, many accounts characterise the boundary between experimental and related activities to be imprecise, if it exists, and therefore not a useful distinction. (For what is the status of reading, for example, or becoming informed?) On this argument, scientific activity is difficult to define narrowly as merely experimental or laboratory activity. Secondly, other accounts of scientific activity do not even begin with the minutiae of experimentation or logical reasoning, which are assumed. These accounts are concerned with other activities by which experimentations are established and their results accepted or rejected, and in other ways manipulated. The following argument addresses both of these claims.

Broadening the characterisation of activity from experiment

Earlier in this chapter, we noted that experimental activity not only characterises science in the public mind, but is a leitmotif also in the metascientific literature. However, it is a distortion of the metascientific literature to claim further that activity in science is only experimental or that experiments can be understood by reference only to their logical structure. Much of the literature concerned with experiment does not explicitly exclude other activity, it just does not address it. Conversely, other views in the literature do not deny the centrality of experiment and related activities, but attempt specifically to redress this imbalance. (See Table B.5.1.) As we have seen, the selection of meanings from the summary statements indicates a broader interpretation of activity than methods, the subject of the extract above from Hodes. For example, some authorities identify maintaining, perpetuating and communication as scientific activities. That is, these are activities characteristic of science, although they also characterise other endeavours, and need not be considered a method of science. It is contentious, therefore, to claim that experiment is the only scientific activity, or that experiment can be understood without understanding other activities. In dealing with the nature of activities loosely described as discovery, the preceding section included the argument that a strictly mentalistic or psychological account of scientific activity is inadequate. This section (a) pursues that critique to explicate ambiguities between experimental activity and related activities, leading to broader characterisations of scientific activity; and (b) addresses insights from viewpoints which do not begin from a concern with experiment.

Experiment is less distinct as an activity than once thought

The first critique questions the notion that scientific activity is essentially experimental activity, logically and in other ways separable from other activity. We have
mentioned above the changing interests, as part of post-positivist thinking, in the experiment: in the influence of assumptions and beliefs underpinning the experiment, a re-evaluation of the role of experiment in science, and attempts to detail and understand the elements comprising experiments and laboratory activities more generally. Despite individual differences among views entailed in these developments, an emerging characterisation is that the experiment is more complex and subtle than was previously believed. The implications of this view are that the experiment is subject to a far wider range of influences that was previously thought, and that the experiment itself is not the only activity that influences the production of scientific knowledge. An indication of this progression of characterisation can be found in Chalmer’s (1982) widely-read introduction to some of the major philosophical views of science, in which he addresses, in order: inductivism, Popper’s falsificationism, Lakatos’s research programs, Kuhn’s paradigms, Feyerabend’s anarchism and a variant of modern scientific realism. The sweep of this argument is sufficient to demonstrate the notion of this progression of argument of characterisation, and is given here. The detail of the actual arguments is omitted only to highlight a trend of thought, and the trend itself is not portrayed as a simple linear progression; rather, the examples illustrate ideas the indicate a change in thinking.

Some responses to naive characterisations of experiment

We have noted earlier in this chapter that inductivist characterisations of scientific activity appeal because they fit common sense notions of reliable knowledge, observation, induction, objectivity, and so on. We also noted, however, problems with inductivist claims to sure knowledge, notably that inductive conclusions cannot be logically justified, and that observations are not ‘objective’ as once thought. One response to this dilemma was Karl Popper’s falsificationist methodology, in which both the reliance on induction as the basis for hypotheses, and the theory-ladenness of observations, are immaterial. Hypotheses may be freely conjectured; the significant process is the rigorous testing by observation and experiment of the hypothesis. Those that fail (are falsified) are rejected, and so to be subject to this test, the critical characteristic of scientific hypotheses is that they are in principle falsifiable. However, even the more sophisticated versions of falsificationism have their own problems. For example, observations are not secure enough to support clear falsifications, because the same failings of observations in naive induction also apply here. Secondly, falsifications are difficult in complex situations where individual factors may need to be isolated. Thirdly, falsification poorly represents the historical record.

Imre Lakatos (1974) proposed an account of scientific activity that focuses on the scientific research program rather than on individual experiments, where the research program is the framework within which research is done. The basic assumptions and
defining hypotheses of the program comprise the *hard core*, which cannot be falsified if work is to be done in that program, i.e., they are not to be modified or rejected. The protection from falsification is provided by the initial conditions, auxiliary hypotheses, and so on, that comprise the *protective belt*, which is subject to the testing. The program is *progressive* if work in the protective belt leads to the discovery of novel phenomena, and *degenerating* if not. A difficulty with Lakatos' research programs is judging the time necessary to apply his analysis, for an apparently degenerating program might just become progressive if a single experiment provides the appropriate result tomorrow. However, it provides a better account of the historical record than either inductivism or falsificationism, as does Thomas Kuhn's (1962) characterisation of science by paradigms.

Kuhn originally proposed the paradigm as the general set of assumptions, laws and activities adopted by a community of scientists. He later clarified the term as meaning the *disciplinary matrix* and the *exemplar*. Work done within the paradigm is normal science, which carries on until sufficient discrepancies or problems surmount, leading to a crisis state. Crises are resolved when sufficient scientists perceive a new paradigm to be better, and work in it instead, constituting a scientific revolution. Kuhn therefore characterises science as discontinuous, unlike the steady and incremental progress implied by inductivist characterisations.

The detail of these accounts, and more, is grist for the mill in most metascience texts in recent decades, but the present discussion is included to show: (1) that well-known accounts fit within the schema of this thesis; (2) that, in particular, this sweep of thinking is partly characterised by activity; (3) that the different interpretations use different activities; and (4) the limitations of restricting attention to the application of logic, and that more powerful alternatives arose within the philosophy of science and other traditions.

Thus for example, despite its appeal for addressing some shortcomings in inductivism, *falsificationism* failed in practice to provide the means of distinguishing science from non-science that Popper sought:

> It must also be acknowledged that the much-vaunted distinction between science and pseudo-science is now beginning to look somewhat tatty. One can accept that a theory that is formally unfalsifiable cannot be scientific, but it is often the case that a falsifiable theory is not falsified because its proponents choose not to press home the falsifying evidence - Popper's methodological rules against conventionalist stratagems notwithstanding. They prefer to invoke ad hoc hypotheses, or to conventionalise the theory. But this has to do with aspects of human behaviour, rather than some logical feature of the structure of the theory.

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16 The discussion of boundary work, in the companion chapter on context, shows that essentialist approaches to characterising science, such as Popper's, are all flawed. Scholarship within the field of boundary work suggests that constructivist (descriptive) approaches are more meaningful, although essentialist notions are still held strongly outside this field.
its inherent unfalsifiability. So whether or not theories are falsified on any given occasion is as much a social question as anything else. So, as I say, the distinction between science and pseudo-science should be made by examination of social practices just as much as by examination of the logical structures of theories.

In fact, Popper himself acknowledged this long ago when he wrote:

*Only with reference to the methods applied to a theoretical system is it at all possible to ask whether we are dealing with a conventionalist or an empirical theory.*

With hindsight, this can perhaps be seen to have been the thin end of the wedge of the sociology of knowledge cutting into Popper's theory. Thus, if we want to know whether a theory is or is not scientific, we should look and see how it is handled by people, rather than consider its logical structure. (Oldroyd 1989, p. 315; emphasis in original)

That is, comparison of the idealised method with actual practice meant that (a) the confidence in the scientific results could not be guaranteed, and (b) the logical processes alone are inadequate, and account needs to be taken of a wider context of activity. Hence the increased interest of post-positivist metascience in actual rather than idealised scientific activity. We will examine three characterisations of science as more than just experimental activity. (a) Bhaskar (1975; 1989) is an example of a philosophical critique that claims traditional HPS accounts are inadequate partly because they neglect social characteristics of scientific activity. (b) Ravetz (1971) is an example of a sociological perspective, that begins by acknowledging social activities of science. (c) Recent Australian government policy is an example of an influential characterisation that is in the public domain and simply presumes experimental, social and other characteristics of scientific activity.

*a) Bhaskar's characterisation of science by activity*

Bhaskar has argued that traditional approaches in HPS to scientific activity have in fact removed the intelligibility of activity in science, and that philosophical analysis can both reveal this flaw and show that scientific activity is more than experimentation. In his view, classical empiricism (as in the tradition following Hume) and transcendental idealism (as in the tradition following Kant) are similarly flawed, for several reasons. Both of these traditions, and hence most traditional HPS, seek to justify belief. In doing so, they require that scientific knowledge has secure or certain foundations. This establishes a sequence of requirements: certainty entails, in turn, individual experiences, the events that are the ontological counterparts of these experiences, other events that are their constant conjunctions, and closed systems within which these events occur. The analysis of patterns of phenomena (laws) is therefore anthropocentric, the complement of

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17 Here we might modify Oldroyd's suggestion that we look at the human context *rather than* the logical structure, to suggest the logical structure can be looked at only within a wider context. The present thesis, again, argues that any particular characteristic of science should be analysed only along with other dimensions, such as in this case structure and context.
which 'is neglect of the conscious human activity required for our knowledge of them' (Bhaskar 1989, p. 22). Thus, both empiricism and neo-Kantian idealism share beliefs about the cosmos (that is, an ontology), which Bhaskar calls empirical realism: the world is human-dependent (empirical) and knowledge is activity-independent (asocial).

Against this, Bhaskar characterises science by a version of scientific realism, meaning that it asserts that the objects of scientists' study are real18. It differs from empirical realism in several respects. First, it seeks to analyse the intelligible activities of science - the activities that lead to knowledge about Nature - rather than justifying belief. Secondly, according to Bhaskar, science is intelligible only if it is assumed that 'the order discovered in nature exists independently of [people]' (Bhaskar 1975, p. 27). More specifically, experimental activity is only intelligible if the experimenter is a causal agent of the events in an experiment (a closed system), but is not a causal agent of the tendency to similar events in open systems outside the context of the experiment. The statement of tendency or way of acting of things is the causal law (Bhaskar 1975, p. 51), such as Ohm's Law:

Now an experiment is necessary precisely to the extent that the pattern of events forthcoming under experimental conditions would not be forthcoming without it. Thus in an experiment we are a causal agent of the sequence of events, but not of the causal law which the sequence of events, because it has been produced under experimental conditions, enables us to identify.

Two consequences flow from this. First, the real basis of causal laws cannot be sequences of events; there must be an ontological distinction between them. Secondly, experimental activity can only be given a satisfactory rationale if the causal law it enables us to identify is held to prevail outside the contexts under which the sequence of events is generated. (Bhaskar 1975, p. 33)

That is, there are ontological differences between causal laws, events and the experiences of empirical activity, which indicate three domains of reality or ontology. For example, copper has the tendency to conduct electricity, regardless of whether it is conducting at a particular point in time and space, or whether it is observed doing this.

In Bhaskar's scientific realism, then, there is still a Nature even if there is no science to investigate it:

For it is not the fact that science occurs that gives the world a structure that can be known by [humans]. Rather, it is the fact that the world has such a structure that makes science, whether or not it actually occurs, possible. (Bhaskar 1975, p. 30)

The significant difference from empirical realism is that scientific realism suggests more than one domain of reality.

Bhaskar in fact suggests that there are three domains of reality, as follows, and that this belief has implications for our view of scientific activity. Firstly, we observe that in Nature things have tendencies or ways of acting, which we summarise as statements

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18 Bhaskar classifies his version of scientific realism as transcendental realism or critical realism.
called *causal laws*. For example, copper has the tendency or way of acting to conduct electricity. The way of acting of a thing results from a generative mechanism or its being as a structure (Bhaskar 1975, p. 51). This is the domain of the *real*.

However, although causal laws do not depend on human activity, the events by which we identify these laws in an experiment do depend partly on human activity. Thus, while any number of school students or research assistants may upset the workings of an experiment, this is not taken to show that a causal law has been overturned. Events, then, are real but their ontology is different to that of causal laws. Thus mechanisms or structures may be said to exist whether or not they generate events, and events are neither experiences nor causal laws. Events may occur regardless of whether they are experienced by scientists: they may be unperceived, or in the absence of scientists, unperceivable. The experimental event of an electric current in a copper wire that is subject to a potential difference is not the same as the tendency or way of acting of copper to conduct electricity per se. The reality of events is the domains of the *real* and the *actual*.

Similarly, experiences are also real but they have a different ontology: the mechanisms and structures that cause tendencies and events may occur regardless of whether anyone is there to observe them:

Tendencies may be possessed unexercised, exercised unrealised, and realised unperceived (or undetected) by [people]; they may also be transformed. (Bhaskar 1975, p. 18).

The reality of experiences is the domains of the *real*, the *actual* and the *empirical*.

These domains of reality represent the core of a belief system that is significantly different from that of empirical realism in several ways. First, these domains of reality may be disjunct from each other, implying an ontological difference. For example, beyond the context of the experiment - in open rather than closed systems - copper has the tendency or way of acting to conduct electricity.

Secondly, it is the distinction of these three domains of reality that makes the very idea of experimentation meaningful. The intelligibility of experiments and the ‘idea of the universality of a known law’ (Bhaskar 1975, p. 13) depend on the assumptions that mechanisms are independent of the events they generate and continue to act outside the closed conditions of the experiment. (The present thesis interprets Bhaskar to be saying that experiments are intelligible in terms of the belief system, elements of which are this ‘idea’ and these ‘assumptions’.)

... It is only when the distinctiveness of the domains is registered and the possibility of their disjuncture thereby posed that we can appreciate the enormous effort - in experimental design and scientific education - required to make human experience epistemically significant in science... (Bhaskar 1989, pp. 21-2)

That is, to generate knowledge (to know) from experimental and teaching activities, requires enormous effort which can only be appreciated when disjunctures between these
domains are addressed. Thus, neither performing experiments (in closed systems) nor applying laws outside experimental conditions (in open systems) makes sense unless real structures exist independently of the events they generate. Also, we need to perform experiments because real structures are often out of phase with events. Likewise, making observations does not make sense unless events occur independently of experiences. Experiences are often out of phase with events, as in cases of mis-observation or misidentification; hence the need for scientific training. Empirical realism is a flawed view because (a) it assumes that the world is essentially experienciable, rather than that some things happen to be experienciable and this is significant for science; (b) it uses the category of experience (an epistemological concept) to define Nature (an ontological function); and (c) it neglects 'the (socially produced) circumstances under which experience is in fact epistemically significant in science' (Bhaskar 1975, p. 28).

Thirdly, this views points to a broader range of scientific activities than only experimentation in the production of scientific knowledge. Scientific realism, on the contrary, proposes that 'science is not an epiphenomenon of nature, nor is nature a product of man' (Bhaskar 1975, p. 25). That is, scientific realism seeks to reconcile the social production of knowledge of an objective world (causal structures and things). Conversely, neither empiricism nor neo-Kantian idealism 'can sustain the idea of the independent existence and action of the causal structures and things investigated and discovered by science' (Bhaskar 1975, pp. 27-8). It is critical because it precludes any analysis that might illuminate the significant activities in science:

... Now this double reduction prevents the empirical realist from examining the critical question of the conditions under which experience is in fact significant in science... It is evident that the critical omission from orthodox accounts of science is the notion of scientific activity as work. Moreover, when, as in transcendental idealism, work is recognised, it is treated only as intellectual, and not also as practical labour, in causal exchange with nature. Accordingly, such accounts cannot see knowledge, or at least the achievement of a closure, as a transient social product. Underlying the undifferentiated ontology of empirical realism is thus an individualistic sociology, in which people are regarded as passively sensing (or else, conventionally deciding upon) given facts and recording their constant conjunctions, that is to say, as passive spectators of a given world, rather than as active agents in a complex one. In the ensemble of conditions and concerns that constitute empirical realism, it is this model of tacitly gendered man that plays the dominant role. (Bhaskar 1989, pp. 21-22; emphases in original)

That is, traditional empiricist and idealist accounts fail to identify just what and how experimental activities lead to the production of knowledge about Nature. This arises partly because, instead of analysing intelligible activities as Bhaskar and others seek to do, traditional HPS accounts aim to justify belief.

In conclusion, Bhaskar's post-positivist philosophical analysis argues that traditional philosophical analyses of science are inadequate both because they fail to show
both why experimental activity in science is significant, and the significance and social character of experimental activity as work. Traditional, empirical realism, that assumes the world is human-dependent (empirical) and knowledge is activity-independent (asocial) is therefore unable to account for the significance of experimental activity. Conversely, scientific realism, that assume the knowledge is human-dependent and the world is human-independent (transcendentally real), makes clear the significance of the experiment but also that it is not sufficient to account for science knowledge: social activities have a necessary role. On his analysis, therefore, it is a misrepresentation of scientific activity to consider only experiment; other activities, such as negotiation, training and organisation, are also significant in determining the knowledge outcomes of science.

b) Ravetz's characterisation of science by activity

Another source of argument that scientific activity is more than just experimental is the approach from the view of science as socio-cultural practice. Science as socio-cultural practice is one of four models proposed by Gallon (1995) as his typology of STS models for the dynamics of science, all of which characterise science partly by activity, but with emphases on different sorts of activity (see Table B.5.1). As with the discussion of Bhaskar's scientific realist account, above, an outline of one account will be made from the many available, to illustrate the use of this activity in characterising science. The particular example is Ravetz (1971), which has been an influential account and is still a persuasive characterisation of science in terms of socio-cultural activity (Gallon 1995). Ravetz's introduction provides a rationale that fits very well with the rationale of this thesis in the emerging complex of interactions with science by the general public. Ravetz is in some ways interpretatively dated: much work has been done since in STS, for example, in developing characterisations that no longer see science and culture as separate, that speak more of sciences and less of science, and in elucidating the 'micro-activities' in laboratories and consensus formation in scientific disciplines. Nonetheless Ravetz has been influential in broadening the scope of the notion of scientific activity and is a useful example of this characterisation of science for the present thesis.

Ravetz made two main arguments. First, he proposed that the 'deepest problems [of science] have changed from the epistemological to the social' (Ravetz 1971, p. 10). This arose from his concern that science has changed fundamentally in the twentieth century, in particular its massively increased capacity to influence society (see summary statement 110). Thus, like Bhaskar, he argued that science is not best understood by focusing on truth-seeking:

To achieve an understanding of the new social character and problems of science, it is useful first to review the deficiencies of the various prevalent common sense and traditional images of science; and then to show by example that the industrialised science of the present has social problems which arise
from the technical and social conditions of its work. This discussion opens the way to a new philosophy of science which, instead of asking ‘What sort of truth is embodied in perfected scientific knowledge?’, proceeds by asking ‘By what activities and judgements, individual and social, can genuine scientific knowledge come to be?’ (Ravetz 1971, p. 10)

Thus activity is fundamental to Ravetz’s characterisation of science (work, activities and judgements), although his account starts with concerns characterised by context (industrialised science of the present, social problems, technical and social conditions, and individual and social) implicit elements of a belief system (criteria for judgements) and knowledge. Again like Bhaskar, Ravetz is concerned to resolve ‘the paradox of the radical difference between the subject, intensely personal activity of creative science, and the objective, impersonal knowledge which results from it’, which had been ‘ignored in philosophical discussion’ (Ravetz 1971, p. 75). However, his different question results in a different answer: that scientific activity has characteristics of craft activity that are ignored in traditional characterisations. Thus science is characterised by ‘a special sort of craft work operating on intellectually constructed objects’ (Ravetz 1971, p. 146). The craftswoman or craftsman (craft worker does not imply the same richness of expertise) has a knowledge of his or her materials and tools that is often intimate, personal, tacit and informal, combined with skills and attitudes refined through experience, and often affected by personality, availability of particular resources, and so on. A sympathetic characterisation of this interplay is given in Pirsig’s more widely-known polemic, Zen and the Art of Motorcycle Maintenance (Pirsig 1984).

For Ravetz, craft activity is directed toward (or in the terminology of the present thesis, has the purpose of) solving problems, and comprises an ‘interplay of personal and social aspects [that] begins with the birth of the problem itself and is continuous through the inquiry’ (Ravetz 1971, p. 76). Thus the collection and refinement of data, refined data being information, involves not just mechanical or technical activities but also making judgements and the judicious application of craft skills. These activities are carried out using tools, which include: the physical apparatus that produce the data; data-processing tools such as statistical techniques or hardware that produces patterns; tools for interpreting data, such as standard information; and tools such as calculus for manipulating formal languages such as mathematics. Such tools require considerable specialisation of expertise, which emphasises the social character of these activities:

Because so many of the essential tools for any field of science are so highly sophisticated, to achieve complete mastery in the use of some of them involves becoming a specialist in the tool rather than in the field to which it is being applied. There is thus a natural division of labour between tool-experts and their clients; and the tools experts are not merely individuals serving as auxiliaries to the clients in the work, but themselves can form a self-contained speciality, a tool-providing field. When two craftsmen [sic] with different skills are involved in the same project, they will inevitably see the work from different points of view. The different approaches will be complementary, and can correct and
enrich each other; but they can also be the occasion of conflict. (Ravetz 1971, p. 90)

The degree of specialisation is characterised by activities deploying tools: where the specialisation is less marked, a preferable characterisation is to speak of *tool-users* rather than tool-experts and clients.

Changes in fields or disciplines are characterised also by activities deploying tools:

> We have already seen that in a general way the tools available define the range of problems that can be studied. But the influence of tools on a field can be more subtle than a mere creation of possibilities. The extensive use of a tool involves shaping the work around its distinctive strengths and limitations; one can rarely apply a new tool to an existing stream of research without modifying the stream strongly. Hence as new tools come into being, and are judged appropriate and valuable by the people in the field, they alter the direction of work in the field and the conception of the field itself. The men of an older generation who cannot master the new tools may grumble that the field has been distorted or taken over by outsiders. (Ravetz 1971, p. 93)

The characterisation of scientific activity as craft activity is made in other ways also: the notion of ‘pitfalls’ or ‘concealed traps for the unwary’ or un-initiated (Ravetz 1971, pp. 94ff); the mastery of tools, which entail ‘informal and largely tacit precepts’ (p. 103); and the existence of individual style in setting and solving problems, writing up the work, and in interpersonal and social relations.

Ravetz’s notion of craft skills is less significant in itself than in its role in identifying their decline in the increasingly industrialised character of science following World War II. That is, it is partly by this characterisation in terms of activity that Ravetz argues for a fundamental change in the nature of science itself. This is what Redner (1987) referred to as the *technification* of science, mentioned above:

> Technification in the natural sciences - despite its undoubted achievements - is causing serious problems even in standard scientific work. Ravetz has explored at length the problems of what he calls ‘industrialised’ science, which is very largely technified science. The loss of skill and craft competence among the general run of research workers as a result of the over-utilisation of big machines, methodical techniques and routines of organised research procedure is gradually revealing all the symptoms of work in bureaucratised organisations. There is a diminution of inventiveness, a lapse of personal responsibility, over-authoritativeness, and, eventually, an absence of purpose. Such science cannot even serve practical ends adequately, for as Ravetz points out, there is a ‘tendency for immediate technical problems to displace the initiating practical problem in the execution of a project [which] becomes very marked as soon as a stable organisation has been formed, and “welfare invention” has given way to “welfare engineering”’ (Ravetz 1971). (Redner 1987, pp. 70-1)

Thus the partly tacit and social character of scientific methods, identified as characteristics of craft activity, is particularly significant in this, the first argument of Ravetz’s characterisation of science. It illuminates some of the character of scientific activity and, as a result, also some fundamental changes in scientific activity. Redner extends Ravetz’s argument to further claim that the progressive replacement of these craft activities, with
the accompanying loss of craft skills as scientists and technicians work as teams on ‘big machines’, contributes to a fundamentally different character of science.

The second of Ravetz’s arguments for the social character of scientific activity is that scientific inquiry is ‘a special sort of socially organised activity’, arising from ‘the distinction between the collective goals of that work, and the private purposes of each of the agents involved in it’ (Ravetz 1971, p. 243). This is an example of the second critique of scientific activity, to which we now turn, that does not begin with experiment and does not necessarily claim that scientific activity is to be understood only from within the context of the practice of science. Appendix B.1 on context mentions examples found through historical studies of the influence of ‘external’ or socio-cultural factors, and goes further to show that the notion of external versus internal factors is highly problematic. Even more significantly here, there are abundant examples to show that science as practiced in the latter half of the twentieth century is inextricably enmeshed in socio-cultural, political, military, industrial and other factors.

This argument, that the substantial portion of funding for science comes directly from large social institutions like governments and industrial corporations, gives a clear picture of strong influences on scientific activity. From this perspective there is only secondary interest in the logical structure of experiments or the refinement of technique. The primary interest is in directing scientific activity towards this problem and not that one, on directing funding to this research project or team and not that one, and on procuring this set of information or this product, under specified conditions such as time, confidentiality or cost:

The success and vigour of scientific research, and the effectiveness of its technological application, are generally accepted as indicators of the quality of a nation’s life. Science is so important, and expensive, that the major policy decisions concerning its development are increasingly being taken by the State, rather than being left to the judgement of the scientists and their private patrons. Accordingly, the progress of science becomes a matter of politics; everyone in the community is involved in the consequences of decisions on ‘science policy’, and every citizen is responsible, however indirectly, for the formation of those decisions. This social involvement of science will necessarily increase over the decades to come. An increasing number of practical problems will need to be solved through planned programs of scientific and technological research, and the rising cost of the many-sided work of science will call for the most direct involvement of the State in its planning. (Ravetz 1971, p. 11)

From this perspective, other sorts of activities also characterise science. Ravetz addresses four groups of such activities according to particular purposes needing to be met: activities for protecting property, managing novelty, controlling quality and (although not addressed explicitly in terms of activity, nonetheless entailing activities in) maintaining ethical frameworks. These are described in Appendix B.3, but briefly here they include the following.
The *generation of publications* such as articles and research reports, itself a collection of activities, constitutes the *creation of a product* which in turn needs to be *authenticated and protected*, activities which by their very nature are social. The generation of new or novel results in science is in some respects like any other creative human activity, but there are issues concerning its management that science shares with few other human activities:

But in science, the achievement and management of novelty do present problems which are nearly unique. In other sorts of work, an organisation can be quite successful even if it merely keeps pace with gradual changes in circumstances, and does its old job well; but in science, a field in that condition eventually comes to be judged as stagnant. Also, in science, the achievement of novelty of any significant sort involves a challenge to some existing intellectual property; and the task of the management of novelty involves the orderly destruction of personal property, for the fulfilment of the collective goals of the work. (Ravetz 1971, p. 260)

This characterisation has become strained somewhat in the quarter-century since it was written. It seems reasonable to argue that at least since the mid-1980s, public and private sector reforms in countries such as Australia have seen accelerating rates of change, such that the *keeping pace* Ravetz describes would be judged as insufficient in many more activities now. In defence of his argument, the pace-setters for change in industry largely comprised those with strong research bases in science - electronics, biotechnologies and materials sciences are obvious examples - for which keeping pace means a strong commitment to research and development. The management of the change, though, remains pertinent, because the creation of new knowledge very often entails the discarding of the established knowledge, activities which by their nature will create tensions. Histories of science are replete with accounts of these tensions and their resolutions in scientific communities (and wider communities); again, both the intellectual and the social character of these activities is fundamental.

*Quality control* has been less of an issue than have *protecting property* and *managing novelty* prior to the twentieth century, probably due in part to the ‘idealist propaganda of science’ by which science was characterised as a largely self-regulating activity (Ravetz 1971, p. 273). This view is no longer held as strongly, influenced no doubt by post-positivist critiques of science, and the increasing industrialisation and general public accountability of science. Thus the mechanisms and criteria for assessing and maintaining quality are more widely known now, partly through increasingly public scrutiny. Thus scientific activity is increasingly subject to public scrutiny, such as through the competition for resources and funding, especially through application for grants, and the action and intervention of other groups in society, such as animal welfare groups. These activities affect not only how science is done, but what science is done. While these social effects may have been present in the past but unrecognised, they are now quite evident. Again, they constitute social activities of science.
The matter of ethics in science, addressed by the present thesis in the companion chapter on belief systems and Appendix B.2, is not addressed by Ravetz explicitly or uniquely in terms of activity, but the activities involved in determining, exercising and monitoring ethical principles and standards need to be acknowledged:

The specification and achievement of a set of personal purposes on a job is thus a complex affair, which can itself be considered as a task. The different sorts of activities and unit tasks associated with a job are evaluated by their function in the achievement of the personal purposes, and individual unit tasks will be specified by private goals, established in accordance with these private functions, rather than being defined by those who direct and control the work. (Ravetz 1971, pp. 292-3)

Once again, these activities are inherently social in character, since they apply standards which are communally and consensually negotiated within a shared belief system.

c) The characterisation of science by activity in science policy

Finally is an example of characterising science by activities identified in public policy. An indication of the situation in Australia in the mid-1990s is given in the publications, Australian Science and Innovation Resources Brief 1994 and Innovate Australia: The Pace of Change (both Commonwealth of Australia 1994), and the Annual Report 1994-95 of the Department of Industry, Science and Technology (Commonwealth of Australia 1995), henceforth respectively the Resources Brief 1994, Innovate Australia and the Annual Report 1994-95. Reports such as these make it clear that the Australian government, as with governments elsewhere from about the 1980s, has taken increased interest in how the money provided to support scientific activity is spent. This is manifested as more specific and directed science policy, which directs science funding. It applies to both direct funding, as with cash grants, and indirect funding, as with funding of universities and creation of projects requiring research and development. Thus science funding has come to be seen as a legitimisation of government claims to be a stakeholder in scientific activity, and therefore to have a legitimate say in what scientific activity takes place, and to what purposes. In particular, the Australian government in the 1990s has characterised scientific activity as a factor in the economic growth and well-being of the country:

The relationship between science and technology effort and economic growth including the role of innovation in the growth process is important in national policy considerations. Indicators based on R&D have made an essential contribution to assessment of the health of the national science and innovation system and have helped guide the decisions of policy-makers. Surveys of research and development (R&D) activities have provided the focus for the evolution of science and technology indicators. (Resources Brief 1994, p. 1; opening paragraph of chapter 1, National Overview).

It might be argued that research and development (henceforth R&D) is a broader measure of activity than just scientific activity, and these reports acknowledge distinctions between science and technology. However, it remains that the funding for scientific activity, and
the pressures associated with its dispersal, is part of this mix of money. Thus from this perspective, we do not look to the manipulation of apparatus or subtleties of reasoning to indicate scientific activity, let alone the quality of such activity. Instead, government and other agencies examine other 'indicators' of R&D activity, as given in the Resources Brief 1994. See Figure Activity 1.

These data were collected by the Australian Bureau of Statistics (ABS), whose R&D surveys conform to standards formulated by the Organisation for Economic Co-operations and Development (OECD):

The OECD defines Research and Experimental Development (R&D) as follows: Research and experimental development comprises creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man [sic], culture and society, and the use of this stock of knowledge to devise new applications. Any activity classified as R&D is characterised by originality; it should have investigation as a primary objective and should have the potential to produce results that are sufficiently general for humanity's stock of knowledge (theoretical and/or practical) to be recognisably increased. The outcome of R&D activity is new knowledge, with or without a specific practical application or new or improved materials, products, devises, processes or services. (Resources Brief 1994, p. 69)

This definition clearly avoids the problems arising from a distinction between pure and applied research or from boundary concerns - arguments about whether particular activity is properly ascribed to science or technology or some other related enterprise. Simply, it includes what would be agreed generally as scientific research.

This approach to scientific activity leads, in turn, to different complexities in characterising science, particularly when compared to positivist accounts of experiment and explanation. For example, the identification of scientific activity with economic activity leads to the notion of science as intellectual property (Etzkowitz & Webster 1995). Thus the traditional scientific activity of contesting knowledge is carried out not just for symbolic or epistemological reasons, but also for economic reasons. Knowledge, therefore, is capitalised, which draws attention to the different sorts of activities that comprise three stages of capitalisation.
Appendix B.5: Activity

Figure 10.1
Indicators of R&D Activity, including scientific activity, given in the Resources Brief 1994

- consumption of money earmarked for research and development activities (A$2274 million from the Commonwealth Government in 1990-91)
- consumption of money for R&D according to ‘socio-economic objectives’ in all sectors (defence, economic development, national welfare and advancement of knowledge)
- consumption of money for R&D according to field of research in non-business sectors (in two groups, natural sciences/technologies/engineering, and social sciences/humanities)
- human resources engaged in R&D (full-time equivalent total personnel and scientists/engineers by sector, support staff per researcher, migration of engineers/scientists/academics to Australia)
- comparisons of international rankings for gross expenditure on research and development as a percentage of GDP
- international comparisons of growth in R&D and patenting
- expenditure by the business sector on R&D over time and as a percentage of GDP
- expenditure by the government sector on R&D over time and as a percentage of GDP
- flow of funding support for R&D, from appropriations and other legislation, to various agencies (government, semi-government and non-government) and ultimately to cooperative research centres established through government initiatives
- expenditure by the higher education sector on R&D over time and as a percentage of GDP
- expenditure (‘performance’) by the higher education sector according to socio-economic objectives and by field of research (categories as above)
- measures of support for academic researchers and of postgraduate research students
- measures of total expenditure, total human resource effort and human resource effort by type, for field of research (where ‘effort’ is measured in person years)
- measures of graduate completions of degrees (PhD, master and bachelor, over time and against other countries)
- expenditure and human resources in R&D in non business sectors by socio-economic objective
- expenditure and human resources in R&D in business sectors by product field

The first stage is securing knowledge as private property, typically by patents and copyrights applying for specified periods:

Through these mechanisms, a particular technique for producing antibodies that can fight cancer cells can take on the status of ‘property’. Intellectual property is not only owned but, as such, carries all the exploitation rights ownership normally confers: It can be invested; it can be exchanged wholly or partly for other goods, services or money; and it can be used to prevent other, similar
Appendix B.5: Activity

ideas from trespassing on its intellectual domain, through being granted patent protection. (Etzkowitz & Webster 1995, p. 483)

The marked increase in patenting activity in many countries from the 1980s is well documented (Etzkowitz & Webster 1995, pp. 483-4).

The second stage in the capitalisation of knowledge is accruing value from secured knowledge, typically ‘through marketing and licensing activities’, notably with increasing attention to strategic and applied research.

The third stage is renewing and increasing the value of the knowledge, not as developed as the first two stages, but typically ‘involving coordination among industrial, academic, and government actors’ (Etzkowitz & Webster 1995, p. 484). Although government coordination was typically resisted by capitalist countries such as the UK and USA, it is increasingly identified ‘worldwide’ (Etzkowitz & Webster 1995, p. 485).

These activities lead, in turn, to other activities undertaken that enable scientific success in terms of securing the research funding. Thus the traditional credit earned by publication activity acquires added value in terms of accumulating the ‘credit’ necessary to win competitive grants. This, and the increasing recognition of scientific work by holding patents, encourages research by stable research groups rather than individuals:

What is, however, perhaps most noteworthy about today’s science is that many claims to ‘credit’ that previously would have been recognised only eponymously - as in ‘Boyle’s Law’ or ‘Einstein’s theory of relativity’ - are recognised as belonging to a certain scientist, or team of scientists, because of the patent they hold on it - such as the Cohen-Boyer patent on DNA cloning techniques. Gaining ‘credibility’ in science is increasingly tied to the ability to generate exploitable knowledge, making scientists more akin to ‘economic’ entrepreneurs. (Etzkowitz & Webster 1995, p. 487)

The trends to characterise science increasingly in terms of intellectual property and commercial potential are widely discussed in the STS literature, which suggests five socio-economic activities as contributing (Etzkowitz & Webster 1995, pp. 494ff). First, much new research is not well-characterised by a distinction between pure and applied, and is increasingly underpinned by combined and generic scientific/technological knowledge. Secondly, there are new divisions of labour, and distinctions between public and private-sector research activity are increasingly blurred. Thirdly, production activity in capitalist organisations is changing to a more flexible, post-Fordist (non production line) character which suits closer ties between universities and industries. Fourthly, research activity is increasingly competitive, with the decline of set grants and the pressure for universities to seek external funding. Fifthly, universities have acted in some places, notably in the UK and USA in the 1980s but more widely since then, as regional focuses for research in place of direct government intervention in research.

Etzkowitz and Webster concluded that this new conception of scientific activity is displacing traditional notions of capital and labour, and the activities associated with the generation of knowledge give rise to significant questions about the role, place and
control of such knowledge in society. The 1990s, for example, has seen significant public debate about the information society, the information superhighway and control of telecommunications. We have not seriously addressed other characterisations of scientific activity in STS accounts, but their diversity (see Gallon, above, and in Table B.5.1) provides a range of insights into, and perspectives on, scientific activity beyond experiment.
### Table B.5.1

Examples of characterisation of key metascientific viewpoints by activity

<table>
<thead>
<tr>
<th>Author</th>
<th>Viewpoint</th>
<th>Distinguishing activity</th>
<th>Identified in the work of</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suppe 1973, 1979</td>
<td>Received View (RV)</td>
<td>induction, justifying, confirming, reduction of theories, as what should happen</td>
<td>Carnap</td>
</tr>
<tr>
<td></td>
<td>sceptical descriptive</td>
<td>various; actual rather than ideal activities</td>
<td>Achinstein, Rapoport</td>
</tr>
<tr>
<td></td>
<td>Weltanschauungen (world view)</td>
<td>various; scientific activity within conceptual perspective</td>
<td>Bohm, Feyerabend, Hanson, Kuhn, Popper, Toulmin</td>
</tr>
<tr>
<td></td>
<td>semantic or model-theory</td>
<td>various; description of indicative, abstracted activities</td>
<td>Beth, Suppe, Suppes, van Fraassen</td>
</tr>
<tr>
<td></td>
<td>historical realism</td>
<td>actual practices, both historical and contemporary</td>
<td>Lakatos, Shapere, Toulmin</td>
</tr>
<tr>
<td></td>
<td>idealism</td>
<td>reasoning from mental constructs or ideas</td>
<td>Berkeley, Fichte, Hegel, Hume, Kant, Plato, Schelling,</td>
</tr>
<tr>
<td></td>
<td>realism</td>
<td>reasoning (Platonic realism)</td>
<td>Aristotle, Bachelard, Bhaskar, Duhem, Feyerabend, Hanson, Harré, Hesse, Hume, Kant, Koyré, Kuhn, Plato, Popper, Putnam, Quine</td>
</tr>
<tr>
<td></td>
<td></td>
<td>observation (Aristotelian realism)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>perception (perceptual or empirical realism)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>perceptions and other activities, including social activities (scientific realism)</td>
<td></td>
</tr>
<tr>
<td>Nussbaum 1989</td>
<td>rationalism</td>
<td>reasoning</td>
<td>Descartes, Kant, Plato</td>
</tr>
<tr>
<td></td>
<td>empiricism/positivism</td>
<td>observation</td>
<td>Bacon, Comte, Hempel, Hume, Locke</td>
</tr>
<tr>
<td></td>
<td>constructivism</td>
<td>construction of knowledge</td>
<td>Kuhn, Lakatos, Popper, Toulmin</td>
</tr>
<tr>
<td>Boyd, Gaspar and Trout 1991</td>
<td>post-positivist consensus comprising (a) post-positivist empiricism (b) neo-Kantian constructivism (c) scientific realism</td>
<td>Explain experimental data that correspond with the facts or with reality, while acknowledging the theory-laden nature of observations.</td>
<td>(a) Carnap, Hempel, Hume, Popper (b) Hanson, Kuhn (c) Boyd, Goodman, Kripke, Putnam, Quine</td>
</tr>
<tr>
<td>Pickering 1992</td>
<td>scientific knowledge as objective (logical empiricism)</td>
<td>‘appraisal of conceptual knowledge claims against observational knowledge ... ideally governed by some logic or method’ (footnote, p. 3)</td>
<td>Kuhn, Feyerabend</td>
</tr>
<tr>
<td></td>
<td>scientific knowledge as relative to culture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>scientific knowledge as relative to interests (sociology of scientific knowledge - SSK)</td>
<td>Barnes, Bloor, Callon, Cartwright, Collins, Garfinkel, Gilbert, Knorr Cetina, Latour, Law, Lynch, Mulkay, Shapin, Woolgar</td>
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<tr>
<td>Callon 1995</td>
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<td></td>
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<tr>
<td>science as rational knowledge</td>
<td>production of statements from the dialogue between humans and Nature</td>
<td>Hesse, Holton, Popper</td>
<td></td>
</tr>
<tr>
<td>science as competitive enterprise</td>
<td>production and competitive evaluation of scientific knowledge</td>
<td>Althusser, Ben-Cole, David, Freudenthal, Hull, Merton, Popper</td>
<td></td>
</tr>
<tr>
<td>science as sociocultural practice</td>
<td>production of knowledge by socio-cultural and epistemic activities</td>
<td>Bachelard, Barnes, Collins, Fleck, Knorr, Kuhn, Mulkay, Pinch, Ravetz, Rudwick, Schaffer, Wise, Wittgenstein</td>
<td></td>
</tr>
<tr>
<td>science as extended translation</td>
<td>activities and interactions of all participants ('actants')</td>
<td>Amaan, Callon, Foucault, Knorr Cetina, Latour, Pickering, Wise, Woolgar</td>
<td></td>
</tr>
</tbody>
</table>
Appendix B.6

Argument from the metascientific literature emphasising the dimension knowledge

Appendix B.6 reviews and analyses some of the argument in the literature that characterises science by knowledge. Although knowledge is one of the two dimensions traditionally used to characterise science, this association did not make the present analysis necessarily easier: tradition is not sufficient reason to substantiate an analysis of this type, and exactly what we mean by knowledge is rarely explained in general science texts, other than to address fields or disciplines of knowledge. When we turn to the metascientific literatures, there are strong and diverse views about the nature of scientific knowledge, whose complexity is compounded by views in other literatures, such as psychology. In informal discussions with a number of scientists and science educators during the writing of this thesis, most viewed scientific knowledge primarily as a list or map of knowledge content, but this characterisation alone is unsatisfactory. With some prompting, most agreed that science knowledge was more problematic than this, as discussed in the metascientific literature, and in any event attempting to provide a comprehensive map of such content could never be definitive. Related to its often unspecified use, the term knowledge is used commonly in conjunction with one or another of several other terms, for example belief, understanding and information, whose meaning and relationship to knowledge are likewise often imprecise and interpreted variously. Appendix B.6 delineates some of these uses and relationships in characterisations of science, and is set out as follows.

B.6.1 Current metascientific views of knowledge
B.6.2 Illustrating an historical tradition of science by knowledge
B.6.3 Knowledge and belief
   a) standard definitions of knowledge
B.6.4 Kinds of knowledge
   a) knowledge how and knowledge that
   b) internalist and externalist theories of knowledge
B.6.5 Knowledge and information
B.6.6 Knowledge and understanding
B.6.7 Knowledge / understanding as concepts and propositions
B.6.8 Knowledge and power
B.6.9 Knowledge as a map of scientific content or topics
   a) current scientific conceptions
6.1 Current metascientific views of knowledge

There are various accounts of knowledge in the metascientific literature. Table B.6.1 presents a summary of various analyses of metascientific viewpoints, to enable some comparisons based on notions of knowledge. Each view addresses at least one aspect of knowledge.

This thesis recognises three main positions in contemporary HPS: post-positivist empiricism, idealism or neo-Kantianism, and scientific realism. In (a) empiricism we gain our knowledge of Nature from experience, emphasising the role of the senses in collecting observational data. We have noted in the companion chapter on activity that most other accounts also hold experience to be an essential, even if not central, dimension of science. In (b) idealism our knowledge is structured by the intellect, as in the theory-laden-ness of observations or the selection and interpretation of observations through a world view or Weltanschauungen. Finally, (c) scientific realism holds that the possibilities of our knowledge are given in, or constrained by, an external reality, but our knowledge of it is produced socially and psychologically.

In contemporary STS, Callon’s (1995) summary of approaches in the field suggests four categories. Thus, where science is characterised as (a) rational knowledge, it concerns knowledge as structured in scientific statements. These statements are most commonly classified as observation statements, that account for experiments and data collection, and theoretical statements, that account for conjectures and generalisations. Production of knowledge is thus production of these two kinds of statements. (b) Where science is characterised as a competitive enterprise, the emphasis is on particular activities of knowledge development: both the production of knowledge as theoretical statements, and the evaluation of this knowledge by a process of competition or struggle. This model is not concerned with the content of the knowledge, which it assumes to be published and judged by colleagues:

These publications are in principle intelligible to specialists in the field. One can make use of the notion of information to speak of their contents. This knowledge or information is characterised by its novelty, its originality, or perhaps its degree of generality. An evaluation of its utility, as perceived by others - scientists or nonscientists - is also possible. This model does not exclude the existence of tacit skills, but this is alluded to without being turned into a specific component. (Callon 1995, p. 36)

Where science is characterised as (c) sociocultural practice, the focus is on the production of knowledge within a broader context than just the production of statements that can be interpreted at face value. This model takes science to be a human activity alongside all other human activities: social factors ‘are as important as the constraints that arise from the order of discourse’ (Callon 1995, p. 42). This model does not accept that science knowledge is given completely in a body of theoretical statements: rather that the meaning
of statements arises partly from their contexts, and that some science knowledge comprises the know-how of scientists. It argues that much knowledge in science is implicit and not codified, as in Polyani’s theory of *tacit knowledge*:

Certain knowledge - for example, knowledge linked to the functioning of instruments or the interpretation of data supplied by these instruments - cannot be expressed in the form of explicit statements. In this view science is an adventure that depends on local know-how, on specific tricks of the trade, and on rules that cannot easily be transposed. Formal statements can only travel and be understood in their instrumental environment and the knowledge incorporated in human beings is the same. (Callon 1995, p. 42)

Where science is characterised as (d) *extended translation*, it concerns the production of statements, as in model (a), but goes beyond the notion of codified knowledge, to account for the ‘nonpropositional elements’ that link and stabilise statements, as in model (c) (Callon 1995, p. 50). Thus it characterises scientific knowledge as networks of statements about the world, that derive their meaning from the coherence between actants (technical devices, statements and human beings).

In common with the approach taken in the other companion chapters, the remainder of this chapter presents some of the ways in which the term *knowledge* is used when characterising science, rather than arguing from philosophical or sociological assumptions. That is, it seeks to show how different characterisations use *knowledge* to mean different things.

### 6.2 The role of knowledge in characterising a western European scientific tradition

As explained in Appendix B.1 on context, most histories of science have been straightforward internalist, Whig histories. That is, they trace the historical development of scientific ideas or knowledge, and tend to trace the successful ideas, meaning those interpreted as precursors of later ideas. Thus these histories characterise the development of scientific knowledge as the progressive march of history. Examples are given in the historical section of Appendix B.1, and in Table B.6.2, which shows how a historical sequence of ideas, structured as knowledge propositions, characterises a history of science. The selection in Table B.6.2 is arbitrary: from the detail included it is clear that any attempt to be comprehensive, even if that were possible, would be beyond the scope of the present thesis. Some entries show a developmental sequence over time; others represent ideas that were rejected after some time. Some historical figures and the knowledge for which they were responsible are very well known, such as Newton and others from the Scientific Revolution, and later figures; others whose names are widely known, such as Aristotle, developed concepts that are not widely understood today except by those who have studied them; and others are mostly unknown except for those who have made explicit studies of their works. For these reasons, the scope of Table B.6.2 covers that which is generally less well known, and extends from the Ionian
Thales, in antiquity, to the early figures of the Scientific Revolution. The last contribution included is that of the great astronomer, Johannes Kepler, because of a particularly insightful quote from Hanson (1958), that concerns the theory-laden-ness of observations, and therefore of scientific knowledge. Hanson observed that Tycho Brahe (1546-1601) and Kepler (1571-1630), representing successive generations of astronomers, saw 'different things at dawn' (quoted in Suppe 1979, pp. 158-9), meaning that the knowledge of one was framed essentially within the Aristotelian/Ptolemaic context and the other within a new paradigm. That is, the 'facts' of observation are stated within a particular framework of concepts and theory, which illustrates a salient point about the nature of scientific knowledge. Finishing with this example lends a nice metaphor about the sun rising and the world turning in the history of science!

Some writers characterise science knowledge by a broader history than just the western European tradition. For example, Ronan (1982) has argued that science exists in every culture, and so it is unsurprising that he saw the beginning of science as long before the Ionians. Significantly, he characterised this beginning by knowledge:

The flame of science, as we have described it, first glimmered some ten thousand or more years ago in the Middle East. It began when man [sic] started to gather knowledge, mainly but not only for day-to-day living. (Ronan 1982, p. 14)

This included descriptions and details of animals and plants, both domesticated and wild, for reasons of their usefulness and sometimes for their intrinsic interest alone. Other knowledge, on Ronan's account, accumulated concerning lifting and moving heavy loads, tanning hides, weaving, firing and glazing pottery, smelting ores, deploying pharmacological substances, and so on. This was very much a practical, experiential knowledge, and one could argue that by definition it has featured through the history of *Homo sapiens*. Others, like Wolpert (1992) reject broader characterisations such as Ronan's. For Wolpert, the western European scientific tradition began with Thales of Miletus, as we have discussed in Appendix B.1 on context. His reason is that Thales sought to explain the material world in 'terms that might be subject to verification', for the purpose of finding 'a fundamental unity in Nature' (Wolpert 1992, p. 35).

The present thesis interprets differences such as these as competing attempts at boundary work, that to be understood need to be analysed for the reasons behind these claims. Ronan argued, in essence, that characteristics of what we current understand as science can be found in many cultures, including very ancient ones. Conversely, Wolpert (p. 124) argued that science is exceptional, because it is counter-intuitive and therefore different to other forms of knowledge, and because it provides our 'best' knowledge of the world. Wolpert characterises the practical, experiential knowledge, mentioned by Ronan, as *technology*, and technology as not-science. These are arguments best understood by considering all the dimensions of the characterisations, such as the six
proposed in the present thesis. When analysed in this way, the different purposes of the authors become clear as attempts to create different boundaries, for different reasons.

6.3 Knowledge and belief

Knowledge is used commonly in conjunction with belief or beliefs. Both philosophical and general uses characterise belief at least partly as a disposition or attitude, such as a conviction or confidence that something is the case, and knowledge as a more certain state than belief. Beliefs are discussed in more detail elsewhere\(^1\), so we need only note here that belief may be thought of as a conviction or acceptance of a claim:

Belief:
1. that which is believed; an accepted opinion.
2. conviction of the truth or reality of a thing, based upon grounds insufficient to afford positive knowledge: statements unworthy of belief.
3. confidence; faith; trust: a child's belief in his [sic] parents.
4. a religious tenet or tenets. (*The Macquarie Dictionary*; emphases in original)

The concern here is the relationship between belief and knowledge, which although common enough in the literature, is made clear rarely except in the literature expressly dealing with knowledge (epistemology).

The classic relationship between knowledge and belief is attributed usually to Plato, who argued 'that knowledge involves true belief but goes beyond it' (Quinton 1988b, p. 279). This relationship is given typically as a distinction between knowledge (*episteme*) and mere belief (*doxa*) or true belief (*orthe doxa*): *episteme* is belief with reasons. However, this is incomplete and misses some of the subtlety of Plato's argument (Tiles & Tiles 1993, pp. 11-19). First, the term *episteme* as used by Plato does not mean simply knowledge, as commonly translated into modern English: rather, it draws on a notion of know-how, which we will address in the discussion below of knowledge-how. Secondly, Plato often used *episteme* in conjunction with, and sometimes interchangeably with *techne*, whose translation into modern English as skill or craft again fails to convey the richer meaning in the Greek:

[T]he exercise of a *techne* involves a process of thought which can generate an account of what it offers, as well as explanations of its procedure based on the nature of those objectives. It is know-how backed up by thought which is able to articulate reasons. (Tiles & Tiles 1993, pp. 11-12)

(It was Plato's pupil, Aristotle, who later distinguished between *techne*, as exercising discursive thought toward producing something like an artefact, and *episteme*, as exercising discursive thought toward producing a rational discourse in the form of demonstration; demonstration communicates *episteme.*) Essentially, Plato viewed knowledge as certain, infallible or more secure than a belief, even when the belief is true:

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\(^1\) See section 6.5, below, and the companion chapter on belief system.
Plato [acknowledges] that, for the purposes of succeeding at what one is doing, a correct *doxa* may serve just as well as *episteme*, but the former is unstable, liable to escape, unless tethered down and turned into *episteme* by ‘working out the reasons’ (*Meno* 98a). (Tiles & Tiles 1993, p. 15)

That is, knowledge is a secure state because it is reasoned. This can also apply in the sense of knowledge being first hand experience, and belief being mere hearsay. For example, if I give directions based on my own experience, they are based on *episteme*, whereas if I do not have the experience, they are based on *doxa*. If following the directions is interpreted as a metaphor for the chain of reasoning that tethers the doxa and converts it into episteme, then one can only have knowledge by basing it on reasoning, and not on the authority of someone else. Similarly, Plato distinguished between *technai* of producing, such as bridle-making, and *technai* of using, such as horseriding. Thus horseriders have *episteme* of bridles, whereas bridle-makers have only true *doxa* - relying on the riders’ knowledge - unless they stop making while they gain the riders’ expertise:

When bridle-makers explain their procedures, and why they adopt the materials and design which they do, they have to rely on principles which belong to this other area of expertise. If they do not possess the horserider’s expertise, they must rely on the horserider’s authority. In that case, when they explain their procedure, they are like the person who gives directions ... on the basis of hearsay. (Tiles & Tiles 1993, p. 15)

Thus knowledge, which is reasoned, is more secure than belief, which is not. From these examples, knowledge is more secure also because it is based on personal experience rather than relying on others’ knowledge.

Another relationship between knowledge and belief is that beliefs, not being reasoned like knowledge, are generally unstated and form part of the assumptions that underpin scientific activity, knowledge and so forth. Traditional positivist accounts assumed a correspondence between scientific belief, knowledge and experimental activity that is challenged in post-positivist metascience:

The study of controversies became the methodological focus of a sociology of scientific knowledge, which developed in the early 1970s and resulted in a thoroughgoing sociological contextualisation of science (see Bloor 1976); it examined, for example, how internal scientific standards and experimental evidence fail to provide for scientists’ beliefs (e.g., Collins 1975 and 1981) and how the beliefs and knowledge claims of scientists are influenced by their social context (e.g., Barnes 1977; MacKenzie 1981; Pickering 1984). Unfinished knowledge - the knowledge that is yet in the process of being constituted - on the other hand, became the province of laboratory studies. (Knorr Cetina 1995, p. 141)

That is, the shift from normative to descriptive accounts of science has revealed that, contrary to the positivist RV of science, scientists’ beliefs and knowledge claims do not
correspond with experimental results unswervingly, while they are influenced by social factors.

This relatedness and difference between knowledge and belief is identified in the STS literature as a resource in science-based disputes: belief is held to be less scientific, even unscientific, when compared with scientific knowledge. For the present thesis, science is characterised commonly by belief systems, albeit not as commonly or explicitly as by knowledge, and also by other dimensions. That is, knowledge and beliefs characterise science in two senses: in the broader sense that knowledge and systems of belief are two of several dimensions of characterisation, and in the narrower sense that knowledge and belief are related mental states. One does not cease to have beliefs when one has knowledge, nor are beliefs unscientific: indeed, the present thesis argues that scholarly characterisations of science include, not preclude, scientists having belief systems. Arguments about beliefs being ‘scientific’ or not (and the discussion in Appendix B.1 on context has shown that agreement on this is difficult) are arguments about the contents of the beliefs and other elements of the belief system like criteria.

**Standard definitions of knowledge**

This relationship between belief and knowledge was embodied in the definition of knowledge that until recent times was almost universally agreed in philosophy, that is, in epistemology. The standard view was that knowledge, at least of propositions\(^3\), entails belief or belief-like attitudes such as psychological certainty, conviction or acceptance (Luper-Foy 1992, p. 234). That is, to know something is also to believe that it is so. Thus, the so-called *standard analysis*, or *tripartite definition*, of (propositional) knowledge defines knowledge in terms of belief, following Plato, Kant and others:

The tripartite definition of knowledge states that propositional knowledge, i.e. knowledge that \(p\), has three individually necessary and jointly sufficient conditions: justification, truth and belief. In short, propositional knowledge is justified true belief. The belief condition requires that anyone who knows that \(p\) believe that \(p\). The truth condition requires that any known proposition be true. And the justification condition requires that any known proposition be adequately justified, warranted or evidentially supported. (Moser 1992, p. 509)

That is, on the standard analysis, we *know* a proposition when we have *justified true belief* of it: when we believe it, we are justified in believing it, and the subject of the belief is true\(^4\). This is consistent with the RV of science knowledge, that a scientific theory (that

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3 Propositions are statements having the phrase *that* \(p\), as in *I know that p is the case*. We will return to propositions in section 6.7, below.

4 The three conditions of knowledge are important. (1) We know something when we have a conviction that it is true or believe it: it may well be true but if we don’t believe it we do not have knowledge of it. (2) We must have sound reasons or are justified in having the belief, such as support of evidence: it is possible for us to believe, but have faulty reasons for doing so, and so we do not have knowledge of it. (3) The subject of the belief must be true: we may well have
Appendix B.6: Knowledge

is, its set of laws, axioms and correspondence rules) is empirically true if it truly describes ‘conditions obtaining in the world’ (Suppe 1979, p. 94). That is, science knowledge is true knowledge because it comprises true and justified beliefs. This identification of science knowledge with truth partly explains the residual appeal of the positivist RV:

Nature is assumed to hold a unique truth and the current state of scientific knowledge is assumed to be the best available approximation to that truth. There is no need to examine why scientists believe what they believe, because there are assumed to be no social factors intervening between nature and scientific truth. (Martin & Richards 1995, p. 510)

The positivist approach assumes there is an objective scientific truth that, sooner or later, will be revealed … (Martin & Richards 1995, p. 520)

The epistemological specialness of science rests on the claim that science is a search for truth. This ‘truth’ is believed to be public, testable, and universal rather than merely particular or parochial in nature. Implicit in this conjunction of truth and science is that science is good because the truth is good in its own right. (Bimber & Guston 1995, p. 556)

However, the tripartite definition of knowledge is no longer universally endorsed. First, it was subject to telling criticism. In 1963 Edmund Gettier published some counter examples of having justified true beliefs that are not certain knowledge, and philosophy has not agreed yet on a solution to what became known as the Gettier problem. Most attempts to solve the Gettier problem have been to suggest a fourth condition (Pollock 1986, p. 9). An example of such a fourth condition is that we should also require the totality of truths that sustain the justified true belief. That is, there should be counter propositions to restore the justification for believing all propositions weakened by Gettier propositions (Moser 1993, p. 158-9). However, some accounts deny that knowledge entails belief (Luper-Foy 1992, pp. 234-7).

Secondly, post-positivist accounts of science have questioned not only belief, but the notions of objective truth and justification. The strong version of this view emphasises the negotiated and contested character of science knowledge:

The old understanding assumed that good science produced truth and that truth-producers deserved a special role in politics. The new understanding treats scientific knowledge as a negotiated product of human inquiry, formed not only via interaction among scientists, but also by research patrons and regulatory adversaries. If all scientific knowledge is negotiated, then its content depends in crucial ways on how negotiating authority is distributed. (Cozzens & Woodhouse 1995, p.534)

A weaker version of this view acknowledges the negotiation of knowledge, but also that within the science community, empirical evidence is central to this negotiation. A main justification in believing a proposition, but if it is false, we do not have knowledge of it. (Moser 1993a, 1993b)
difference between the two versions is whether or not ‘research patrons and regulatory adversaries’ play a direct role in constituting science knowledge. The strong version argues that they do; the weak version accepts that their role does affect science knowledge, but only as external agents to the work of the scientists who make science knowledge. We will return to these critiques later in this chapter. The significant point here is that these views presume neither the existence nor the possibility of absolute truth or justification: science knowledge is accepted as the best available and justified fit to empirical results, and not as absolutely true. In this view, definitions of knowledge like the tripartite definition are not relevant.

6.4 Kinds of knowledge

In discussing kinds of knowledge, the present thesis concerns itself with how knowledge is characterised in the metascientific literature, whether there is a characteristic kind of scientific knowledge, and if so, the nature of this scientific knowledge. As a first approach, one could search for examples of knowledge called science, and as we shall see, such examples can be found. However, the notion that there is a kind of knowledge simply identified as science is opposed by much of epistemology, the branch of philosophy that addresses knowledge, and the field of STS. Instead, the present thesis argues that science is characterised by certain kinds of knowledge, but not simply so: (a) not all kinds of knowledge characterise science; (b) the kinds of knowledge by which we characterise science are not unique to it, and are found also in other fields; and (c) science is characterised by these kinds of knowledges in combination with certain structures, contexts, purposes, belief systems and activities. When we examine the literature, we find discussions of several kinds or types of knowledge, and some of these are used to characterise science.

Hirst’s forms of knowledge

There are examples of characterising kinds of knowledge where one kind is labelled science. A notable example in the philosophy of education is Hirst’s (1974) conception of the school curriculum as seven forms of knowledge, of which science is one:

1. mathematics and logic (deductive/analytical forms of knowing in which relations are expressed symbolically)
2. physical science (empirical forms of knowing in which truths are tested by observation and experiment)
3. history and the human sciences (forms involving propositions connected with intentions)
4. literature and fine arts (aesthetic forms)
5. morals (rationally deduced form a broad base of other understandings)
6. religion
7. philosophy.

Hirst argued that these are logically separated, and non-overlapping, because they are based on different conceptual frameworks and tests for truth. The present thesis interprets this as a characterisation by knowledge in combination with structure (conceptual framework), activity (testing) and belief system (criteria for truth).

However, there are strong arguments opposing any essentialist notion of characteristic scientific knowledge such as Hirst’s. First, Hirst’s criteria appear arbitrary, and so the character and number of his forms appear arbitrary (Evers & Walker 1983) even though some commentators see them as useful nonetheless (Mackenzie 1985). Secondly, the HPS and STS literatures have pursued other questions and developed other conceptions of knowledge that are significant, as shown below, yet seem ignored by characterisations such as Hirst’s. Thirdly, the present thesis argues that characterisations of that type are inadequate compared to the post-positivist accounts in HPS and STS fields. Therefore Hirst’s criteria for forms of knowledge appear arbitrary and weakly defended for the present purpose.

Justification of knowledge in traditional epistemology

Pollock (1986, p. 10) has argued that the primary concern of epistemology has not been knowledge itself, but instead ‘deciding what to believe’, or how we justify knowledge:

The theory of knowledge is an attempt to answer the question, ‘How do you know?’, but this is a question about how one knows, and not about knowing per se. In asking how a person knows something we are typically asking for his [sic] grounds for believing it. We want to know what justifies him in holding his belief. Thus epistemology has traditionally focussed on epistemic justification more than on knowledge. Epistemology might better be called ‘doxastology’ [or the study of beliefs]. (Pollock 1986, p. 7; emphases in original)

Thus Pollock argues that epistemology is a field of theories characterised by the solutions they offer to general problems found in all areas of knowledge; it does not suggest any distinct form of knowledge called science in its own right, as Hirst had suggested. Pollock argues that there are several problems: (i) the nature and legitimacy of reasoning by which a proposition is justified by evidence; (ii) whether or not there are foundations to knowledge (meaning whether knowledge beliefs are based on simple, basic beliefs that require no justification themselves, such as beliefs about perceptions); and (iii) the source of norms that govern our reasoning and by which we justify our beliefs. We will address these matters presently.

Rorty’s rejection of any theory or analysis of knowledge

Some accounts reject the possibility of a theory of knowledge, and hence epistemology and any independent philosophical analysis of knowledge. A notable
instance is the notion of the *death of epistemology*, best known in the work of the philosopher Richard Rorty, that an informative analysis of knowledge is not possible (Williams 1993). This is a constructivist or neo-Kantian argument that theories of knowledge, and indeed the very conception that there can be a theory of knowledge, are constructed; and, therefore, what is constructed can be deconstructed. Theories of knowledge, therefore, are neither significant nor perennial but instead arise from historically and culturally contingent concepts such as rationality. Watson-Verran and Turnbull (1995), for example, have argued that critiques of this kind, that reject objectivity, undermine both the claim of scientific objectivity, and its ideological use in promoting the hegemony of Western culture. However, some post-positivist philosophers who also reject simplistic notions of objectivity argue that analysis of knowledge should be continued and refined, not abandoned: it is both desirable and useful (Pollock 1986; Bhaskar 1989; Tiles & Tiles 1993).

The present thesis suggests two conclusions that summarise this state of theorising about knowledge, particularly as it applies to science knowledge. First, there is a range of views about the nature of science knowledge, and the present thesis is concerned to indicate and analyse this range, not to argue from first principles towards a particular view. This means that the present thesis accepts as one among many the view that there is a characteristic science knowledge, that can be analysed; it does not presume an identifiably distinct science knowledge and then seek to clarify it. Secondly, these views differ in their account of how knowledge arises from particular activities, purposes, contexts, structures and belief systems. For example, the belief system of positivist approaches (as described by Martin and Richards 1993, p. 510) includes the assumption or belief that Nature holds a unique truth and that ‘scientific knowledge is assumed to be the best available approximation to that truth’. In an extreme positivism, as in the RV, the purpose of scientific activity is to develop true and objective knowledge; in either case the underlying belief is that the truths of Nature are eternal and unchanging, as discussed in Appendix B.2 on belief system. An alternative view, more typical of the post-positivist consensus, characterises science as seeking to develop the best available knowledge, meaning to best approximate agreed criteria of objectivity.

**Knowledge-how and knowledge-that**

Different perspectives of knowledge are addressed elsewhere in the present thesis, particularly by different internal structures and different activities in the companion chapters on structure and activity, respectively. These include *empirical knowledge*, *a priori knowledge*, and knowledge arising from *deduction* and *induction*. However, discussions of characteristic structures or associated activities do not address the characterisation of these forms as knowledge. There are different kinds or areas of
knowledge proposed in the literature, based on the different ways in which we know or claim to know, and there are problems with each area (Dancy 1985; Pollock 1986; Quinton 1988b; Dancy & Sosa (eds) 1992). Most kinds are common to most accounts of knowledge: they include empirical/perceptual, a priori, moral, memory, inductive and tacit knowledges. We shall mention here two fairly standard characterisations of kinds of knowledge.

One approach is a standard reference summary of senses of knowledge arising from interpretations of knowing, namely that essentially we can have either knowledge-how or knowledge-that:

One way of distinguishing kinds of knowledge is into practical knowledge-how, propositional knowledge-that, and knowledge-of. However, the various sorts of knowledge-of seem reducible to either to knowledge-how (e.g. knowing Italian) or to knowing-that (e.g. knowing the date of the battle of Waterloo). Within knowledge-that, the prime concern of epistemologists, empirical and a priori knowledge are distinguished and, within each of these realms, the basic or intuitive items of knowledge are distinguished from the derived or inferred ones. A priori knowledge is derived from its self-evident axiomatic bases by deduction; empirical knowledge from uninferred observation-statements by induction. The usually acknowledged sources of empirical knowledge are sense-perception and introspection, while a priori knowledge is said to come from reason. (Quinton 1988b, p. 279)

Thus what is usually characterised as the body of scientific knowledge, that is, its framework of concepts and understandings, is knowledge-that. Note, though, that this does not claim a distinct kind of knowledge called science; knowledge-that is not uniquely identified as science, except in strong positivism. Knowledge-that is the subject of a considerable literature, and is addressed in the present thesis across the companion chapters and their respective appendices: the central empirical character of science in most accounts; debates about the relative status of empirical (inductive) and a priori (deductive) activities; and the commonsense appeal but logically flawed nature of induction.

However, knowledge-how receives relatively scant attention in the literature. We have seen that Plato's conception of episteme was more like the present-day conception of know-how than simply knowledge-that. Probably the strongest current characterisations of science by knowledge-how are strands of interest in some of the (usually) STS literature that address science as work, and include a shift of interest from logical analyses of experiment to analyses of the total interactions in laboratories. For example, Ravetz (1971) has characterised science using craft as an analogy, partly because of the knowledge-how that is typically tacit; the notion of tacit knowledge was introduced by Polanyi (1958) 'to account for the transmission of noncodified information' (Callon 1995, p. 42). Thus although knowledge-how is usually ignored in the philosophy literature, it features strongly in the characterisation of science as work, as influenced by Ravetz:
[W]ithout an appreciation of the craft character of scientific work there is no possibility of resolving the paradox of the radical difference between the subjective, intensely personal activity of creative science, and the objective, impersonal knowledge which results from it. When we think of material objects produced by handicraft rather than by mass-production, we easily appreciate the distinctive features of this sort of work. The craftsman [sic] works with particular objects; he must know their properties in all their particularity; and his knowledge of them cannot be specified in a formal account. Indeed, no explicit description of a craftsman's techniques, and the objects on which he works, can be more than the simplest elements of the subject. They can be useful for the beginner, but he must develop a personal, tacit knowledge of his objects and what he can do with them, if he is to produce good work. Indeed, much of his technique may not even have the character of conscious knowledge; by experience, his hands and eyes have taught themselves. It is this subtle interaction of the craftsman with his material, producing slightly different copies of the same general model, which gives handicraft productions their special charm. (Ravetz 1971, pp. 75-6)

Ravetz observed that notions of talent or personal (tacit) knowledge are hardly implied by the impersonal (acontextual) writings of classical science. To redress this, he gave a detailed discussion of the many individual judgements and expressions of tacit knowledge - that is, examples of knowledge-how - in data collection, calibration and manipulation of instruments, and so forth. Thus, as discussed in Appendix B.5 on activity, Ravetz (1971, p. 103) characterised scientific inquiry as 'a craft activity depending on a body of knowledge which is informal and partly tacit', although he acknowledged that this is not usually interpreted as a characteristic of science:

We have already seen several ways in which the work of scientific inquiry requires knowledge which is learned only through precept and experience in a multitude of particular cases, and which is therefore not 'scientific' in character. (Ravetz 1971, p. 101).

That is, he acknowledges that the normative RV of science allowed only knowledge-that as scientific, whereas his own descriptive view also characterises science by the less formal, less structured, knowledge-how.

The present thesis argues that, in making this claim, Ravetz characterises science by both types of knowledge: mainly knowledge-how in experimental activity, and mainly knowledge-that as it is written up formally. Callon (1995) has shown how Ravetz's characterisation has been extended in the STS literature, to argue that knowledge-that does not show how science is transmitted by enculturation:

For instance, in [Collins' 1974] study of the construction of the TEA laser, he showed that the diffusion of knowledge could not be reduced to the mere transmission of information: 'The major point is that the transmission of skills is not done through the medium of written words'. (Callon 1995, p. 42)

While traditional epistemology was concerned mainly with propositional knowledge-that, newer accounts emerged within post-positivist metascience that argued more complex characterisations. To overlook enculturation, as positivism had done, was to fail to
account for the lengthy and demanding training that scientists undergo before they practice science, and therefore to fail to account for knowledge-how.

As an example of a second approach, Pollock (1986) has categorised knowledge as based on either their source or their method of acquisition. Again, there is no area of knowledge called science. There may be several sources of knowledge: sense perceptions (as in perceptual knowledge); a possible intuitive faculty (as in a priori knowledge); a possible moral intuition (as in moral knowledge); or memory. Knowledge from inductive generalisations differs from the other areas by being distinguished by its method of acquisition.

The source of perceptual knowledge is self-evidently perceptions. Generally its problem is formulated as 'explaining how we can acquire justified beliefs about the external world on the basis of the output of our sense organs', because, although 'we all agree that sense perception can lead to justified beliefs about the world around us ... the details remain obscure' (Pollock 1986, pp. 10-11). One possible criticism comes from scepticism. Much has been written about perceptual knowledge, partly because more is known about the psychology of perception. Appendix B.5 on activity addresses some of the issues arising with perception.

A priori knowledge has a complex role in science. With a priori knowledge there are several problems. First, there is no clear and agreed definition: two common definitions are that a priori knowledge is independent of experience, and based only on reason, but for Pollock these are inadequate. Characteristic examples of a priori knowledge are knowledge of mathematical and logical truths, yet to establish the class by example rather than by definition is unsatisfactory. Secondly, although the claim for an a priori intuitive faculty is psychological, the psychology of acquiring mathematical and logical knowledge is not understood. Quite apart from the difficulties of mathematical proof, there is the difficulty of establishing the basis of the premises on which mathematical proofs are founded. The view that these premises are arbitrary axioms established by convention - conventionalism - was held widely, but is no longer considered plausible. This is partly because of Gödel's theorem:

Gödel's theorem has been interpreted as showing that, for any system of mathematical axioms, the mathematician can know a mathematical truth that does not follow from those axioms; realists argue that the only way this could be true is by mathematical intuition. (Steiner 1993, p. 271)

That is, it appears that in a system of mathematical axioms, a mathematician can know more mathematical truths than what conventionally is agreed the axioms contain. Gödel's theorem formalises a long-recognised paradox in mathematical knowledge (Steiner 1993, p. 271). The paradox arises because, on the one hand, mathematics is continuous with physics, the paradigmatically empirical science, but on the other hand apparently is continuous also with metaphysics: it describes geometric figures like circles and spheres
that are ideal, and numbers that are abstract and apparently not the idealisation of actual objects. More than this, mathematical knowledge has a certainty 'that seems to set it apart from empirical knowledge' (Steiner 1993, p. 270). This presents a problem for naturalism, which supposes a causal interaction between the knower and Nature, because mathematical entities are not part of this interaction; Plato and Kant recognised this. Hence the paradox:

We can, therefore, sum up the paradox of mathematical knowledge as follows: without mathematical knowledge, there is no scientific knowledge - yet the epistemology ('naturalism') suggested by scientific knowledge seems to make mathematical knowledge impossible! (Steiner 1993, p. 271)

Steiner outlines various metascientific strategies for dealing with this. For realists, Gödel's theorem is true only if there is mathematical intuition. For Kantians, mathematical knowledge is necessary for empirical knowledge. For empiricists such as Mill, mathematics is a branch not of logic but of physics, and derives its certainty from its empirical confirmation; it is not metaphysical. For logicists, mathematics is again not metaphysical, and hence is sympathetic to empiricism, but is a branch of logic; it is true by definition. For pragmatists, mathematics is useful, indeed essential, for us to achieve the goals of science and life, in the same boat as science. For instrumentalists, mathematics is a tool for use in sciences and elsewhere, but is not a science in itself. For conventionalists, mathematics is true by convention or agreement.

For much of science, notably experimental science, these variations in interpreting mathematical knowledge and science are not central: they are understood as perceptual knowledge or knowledge from inductive generalisations. However, in theoretical and mathematical sciences, like cosmology and computer science, the interpretation of the role of mathematics is central. Redner (1987) has argued that the increasingly mathematical character of science in the twentieth century has contributed to fundamental changes in science:

The changed character of science in the post-Second World War period entailed a gradual departure from Rationalism and the emergence of a scientific approach characterised by another form of rationality: Rationalisation, also called instrumental reason, formal rationality, and Zweckrationalität... Rationalisation has as its basic defining principles standardisation and exact repetition for it is a commutating and calculating form of rationality.

The rationalisation of the cognitive content of science is closely bound up with the techniques of computation and calculation, above all those involving mathematics. This process takes the form of what Whitley, following Georgescu-Roegen has called arithmomorphism: the tendency towards mathematical formulation of all relations in a science and finally its formalisation as a closed theory. (Redner 1987, pp. 56-7)

Thus in some sciences and mathematics, proof procedures are programmed, and are fully automatic, formalised, processes; Redner argued that this constitutes a change in the rationality or justification of the knowledge (Redner 1987, pp. 56-7). At the very least, it
is clear that the character of knowledge in these sciences is linked fundamentally to the character of mathematical knowledge.

Claims that we can have moral knowledge are also problematic. First, there is no consensus that it exists: for example, Dancy (1985) does not include it. Secondly, it is only weakly supported by psychological explanations. In any event, the role of any moral knowledge in science has not greatly exercised the minds of scientists and metascientists.

The role of memory in knowledge is also unclear. Quite clearly, ‘much of what we know, we know by remembering’ (Pollock 1986, p. 13). The question is whether memory is a source of knowledge (apparent memory), something like the role of sense perception in perceptual knowledge, or whether memory is the calling to use of knowledge already held and acquired by some other means. Again, there is no agreed philosophical or psychological explanation. However, any reasonable epistemological account of reasoning will have to account for the significant role memory plays in reasoning:

[When we reason in accordance with any even slightly complicated argument, we do not hold the entire argument in mind at the same time. We attend to each step individually and rely upon memory to tell us that we got to that step in some reasonable way. (Pollock 1986, p. 14)]

Pollock characterises the remaining kind of knowledge, knowledge of generalisations from induction, by its method of acquisition rather than a source. Inductive generalisations are formed by inferring that a characteristic observed in a sample of objects applies similarly to the wider population of such objects. Either we infer that a property observed in the sample is taken to apply to the whole population, by enumerative induction, or we infer by statistical induction that a property observed in a proportion a/b rather than in all the sample is likely to be found in the same proportion in the wider population. However, while this process seems generally plausible, there is no agreement on a detailed description of how this should work, because ‘the premises of an inductive argument do not logically entail the conclusion’ (Pollock 1986, p. 15). This lack of agreement arises from two questions of continuing philosophical interest: how can induction be justified (the traditional problem of induction, as described by David Hume) and how can the principles of induction be formulated (the new riddle of induction, as described by Nelson Goodman). Because of these difficulties, induction is no longer regarded as the means of generating certain knowledge. However, it retains support both generally, as in the way we generate commonsense knowledge, and in science as the means of generating the best available knowledge given the set of observations.

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5 The process of induction and its difficulties are discussed in the companion chapter on activity; the present paragraph simply sketches some of the character of inductive knowledge.
Internalist and externalist views of knowledge

There is considerable debate over internalist and externalist (e/i) characterisations of science, discussed in Appendix B.1 on context, and much of it concerns the nature and status of scientific knowledge, which we will address here. The terms externalism and internalism are used in three main ways (Bonjour 1993). One refers to theories of justifying knowledge (epistemic justification); the second, closely related to the first, refers directly to theories of knowledge; the third refers to accounts of belief and thought content. The sense described in Appendix B.1 applies largely to the third interpretation, although not clearly so: where internalism holds that the content of scientific knowledge is determined only by the mind of the individual, and externalism holds that this knowledge is influenced by external factors such as the physical and social environments (usually also by internal factors). The e/i distinction is rarely made clearly by epistemologists (Bonjour 1993, p. 132) or consistently in debates within and between groups of philosophers and sociologists of science (Shapin 1992). In spite of these ambiguities, or perhaps because of them, debate about the e/i character of science knowledge is one of the more contentious in metascience. We will examine each of the three broad uses of these terms here.

First is the e/i distinction when justifying knowledge. Here, internalist justification is where all the factors needed to justify a belief are 'cognitively accessible to that person, internal to his [sic] cognitive perspective' (Bonjour 1993, p. 132). In the strong version, the belief is justified only if the believer is aware of the justifying facts, and in the weak version the belief is justified if the believer is capable of becoming aware. Pollock (1986, p. 21) has argued that our grounds for reliably deciding what to believe as knowledge - our justification - must rest at least partly on the existing beliefs we hold. Until relatively recently there was almost consensus among epistemologists that beliefs could be justified only by the beliefs already held by the observer; this is a doxastic theory. This means that if the same beliefs are held in two circumstances, then those circumstances justify the same beliefs, regardless of how other circumstances might change. In this approach, the beliefs are justified either by appealing to basic or foundational beliefs that are privileged and need no justification (foundations theories), or to the way beliefs relate or cohere with other beliefs (coherence theories). Both of these approaches are flawed: beliefs can be held for bad reasons, so appealing to foundational beliefs fails, and it appears that some beliefs rely not on beliefs but perceptions (as in perceptual beliefs) and memory. For Pollock, we do not have to have beliefs about perceptions and memories for them to exist.

Externalist justification is where at least some of the justifying factors are 'external to the believer's cognitive perspective, beyond his [sic] ken' (Bonjour 1993, p. 132);
that is, that the beliefs are justified by more than the cognitive state of the believer, such as its reliability. Thus, externalist theories typically acknowledge both internal and external factors. Pollock rejects externalist justification of beliefs (1986, pp. 133ff.), arguing that justification must be guided by reasons, which is done by appealing to norms: reason-guiding norms cannot be formulated by externalist factors, as in probabilism, and appeal to reliability is redundant because internalist norms are sufficient. The only alternative for Pollock is to justify knowledge with the internal states of the believer (internalism) but not solely by existing beliefs (i.e. by non-doxastic factors). Pollock classifies his theory as direct realism, which holds that perceptual judgements can be made about physical objects directly from perceptual states without mediation by beliefs.

The second e/i distinction concerns theories of knowledge, and is related to the first. Here, an externalist account is given of knowledge, but not of justification; it is possible to make a weaker appeal to internalist justification. This account holds that knowledge is true belief that is not justified but satisfies some externalist condition like reliability (Bounjour 1993, p. 135). It allows that animals and children can have knowledge, although the status of such a knowledge is uncertain.

The third e/i distinction is somewhat different to the first two, and concerns the contents of beliefs and thoughts:

[According to an internalist view of content, the content of such intentional states depends only on the non-relational, internal properties of the individual’s mind or brain, and not at all on his [sic] physical and social environment; while according to an externalist view, content is significantly [but not exclusively] affected by such factors. (Bonjour 1993, p. 136)]

As Bonjour points out, and has been noted previously, the traditional view of content, and indeed knowledge and justification, has been internalist. The main argument for externalism is that we seem to have beliefs about external states - for example, what is being observed, or the points of view of others - that cannot be explained solely by what is happening in one’s brain. The main argument against strong externalism is that it does not account for the content of beliefs or thoughts that emanate from within the brain, such as in reflections or puzzlement. Bonjour argues that an externalist justification is possible.

In the broader sense of externalism and internalism, externalists hold that social, political and other factors (usually including internal factors) determine the content of knowledge. Typically they dismiss the objection that external knowledge cannot be justified rationally, for which there seem to be two main arguments. First, the failure to rationally justify externalist knowledge is irrelevant because, contrary to traditional internalist accounts, rationality is not absolute and unchanging: not only knowledge but norms and concepts of rationality are constructed, and are historically and socially contingent. Secondly, internalist accounts fail to show how scientific knowledge comes
to be, even though most accounts allow internalist (cognitive) factors as part of the explanation. We will sketch a few arguments from some externalist accounts here.

The sociology of scientific knowledge (SSK) now comprises a body of discourse and literature distinguishable within the STS literature as a whole. The traditional accounts of sociology of knowledge treated scientific knowledge as unique because it deals with the objective truths of the natural world (Mulkay 1979); an example is Merton’s (1973) discussion of characteristic scientific norms (Cozzens & Gieryn 1990). The newer alternatives treat ‘the procedures and conclusions of science ... like all other cultural products, [as] the contingent outcome of interpretive social acts’ (Mulkay 1979, p. 91). Examples are Edge and Mulkay’s (1976) linking of small group structures with scientific knowledge (theories), and Knorr-Cetina and Mulkay’s (1983) argument that scientific knowledge in laboratory activities and technical discourse have a social character (both in Cozzens & Gieryn 1990). Hesse’s (1984) review of approaches to socialising epistemology concludes that both internal and external factors can be studied, because any knowledge (cognitive) system, like any social system, is held together by ‘social rules or norms’:

Where a system of knowledge or cognitive belief is either accepted (as in our own science) or claimed to be cognitive in other cultures or by subgroups in our own culture, there can be internal epistemological study of the relations claimed to hold between data, theory and conceptual frameworks, and external explanations of the genesis of concepts and methods, and of the goals and interests served by the cognitive system. (Hesse 1984, p. 24)

Longino (1990, p. 216) has argued that only a social account of objectivity can serve to check the ‘unbridled relativism’ arising from ‘an individualist conception of scientific method and scientific knowledge’. It does this by minimising the influences of the subjective preferences and background assumptions made by multiple individual scientists, which the present thesis interprets as the multiple belief systems of individual scientists:

What is called scientific knowledge, then, is produced by a community (ultimately the community of all scientific practitioners) and transcends the contributions of any individual or even of any subcommunity within the larger community. Once propositions, theses, and hypotheses are developed, what will become scientific knowledge is produced collectively through the clashing and meshing of a variety of points of view. (Longino 1990, p. 69; see also Longino in summary statement 119)

Thus the very activities that produce scientific knowledge cannot be reduced to the psychological activities of individuals because the characteristic qualities of scientific knowledge arise from multiple critical perspectives that are tested in argument. This is essentially a social activity:

[C]riticism from alternative points of view is required for objectivity and ... the subjection of hypotheses and evidential reasoning to critical scrutiny is what
limits the intrusion of individual subjective preference into scientific knowledge. (Longino 1990, p. 76)

In summary, the most plausible view from the current literature seems to be some sort of moderate externalist view of science knowledge, that recognises both the internalist elements of the belief system, such as criteria for judgements, and externalist elements such as the social role of criticism and negotiation. This avoids the logical difficulties of traditional accounts of knowledge, on the one hand, and an unbridled relativism on the other. However, to avoid the extremes, one must be aware of their possibility.
6.5 *Knowledge and information*

Other terms commonly used with knowledge and science, though not uniquely so, are *data, facts* and *information*. These are not equivalent terms, although their meanings are related:

**Datum:**
1. any proposition assumed or given, from which conclusions may be drawn.
2. any fact assumed to be a matter of direct observation.

**Data:**
1. plural of datum
2. figures, etc., known or available; information.

**Fact:**
1. what really happened or is the case; truth; reality.
2. something known to have happened; a truth known by actual experience or observation: *scientists working with the facts*.
3. something said to be true or supposed to have happened: *the facts are as follows*.

**Information:**
1. knowledge communicated or received concerning some fact or circumstance; news.
2. knowledge on various subjects, however acquired.
3. the act of informing.
4. the state of being informed.
5. (in communication theory) a quantitative measure of the contents of a message.

(*The Macquarie Dictionary; emphases in originals*)

There are two senses in which *data, facts* and *information* characterise science: both as a state of knowing and as that which is known. In the sense of a state of knowing, data, facts and information are in a sense the 'raw materials', or elemental contents of (scientific) knowledge. They are necessary for scientific knowledge, although in this context they usually mean a state of certainty less than understanding. Thus, one would expect someone with scientific knowledge to be familiar with agreed propositions or conclusions whose certainty is assured; that is, facts and data. These are units of information that comprise (scientific) knowledge-that. However, they do not entail reasoning or understanding. For example, it is possible that we might reject a quiz champion, who rapidly and correctly recalls facts and data, as possessing scientific knowledge. This is despite requiring the person with scientific knowledge to have possession of the relevant data or facts.

In the sense of that which is known, or available to be known, data, facts and information constitute a body of knowledge, or part of it, that is external to the individual knower. This body is available typically as written text, in books and articles that are
developed and reviewed by scientists, and was mentioned above in some of the approaches described by Callon (1995). This is what Popper called World 3 material:

[I]n scientific work we do not even take our own observations as certain, indeed we do not even accept them as scientific observations, until we have repeated and tested them. In all these respects, then, [science] knowledge is objective. It inhabits the public domain (World 3). It is not in the private states of mind of individuals (World 2). (Magee 1973, p. 71)

That is, Popper makes the distinction, mentioned at the beginning of this chapter, between science knowledge as a state of knowing (World 2) and as the body of collected information (World 3).

The rapid increase in science knowledge

Furthermore, data, facts and information are significant to characterising current science because as the twentieth century progressed the amount of available knowledge and fields of knowledge increased at an increasing rate. This phenomenon is widely known by various terms, all of which relate to science but not uniquely or comprehensively so. They represent attempts to summarise either the rapid transformation (information explosion, information revolution, third industrial revolution, communications revolution) or the resulting new social condition (electronic age, age of information, age of cybernation, knowledge society, techtronic society, information society, service society, post-industrial society); most of these terms date from the 1960s (Marien 1983). The characteristic of science knowledge of concern here - its rapid proliferation - is best described as an information explosion, even though this term applies to more fields than just science.

There are many lists in the literature giving examples of a striking proliferation of knowledge. The message has remained relatively constant since the 1960s, although the examples have become more remarkable as the rate of increase has itself increased:

(A)s far as many statistical series related to activities of mankind are concerned, the date that divides human history into two equal parts is well within living memory. For the volume and number of chemical publications, for instance, the date is now [i.e., 1964] about 1950 ... Another startling fact is that about 25% of the human beings who have ever lived are now alive, and what is more astonishing, something like 90% of all the scientists who have ever lived are now alive. (Boulding 1964, p. 7)

This is modest when compared with data two decades later, such as the following quoted by the former Australian Minister for Science, Barry Jones (1983, pp. 179-181) to illustrate the rate of increase of knowledge:

- the sum total of human knowledge is thought to have been doubling every 50 years by 1800, every 10 years by 1950, every 5 years by 1973;
- all case studies of information increase show a geometric, not an arithmetic, increase, with an exponential curve;
• about 200,000 new theorems were published each year in mathematical journals during the mid 1970s, causing the mathematician Stanislaw to say this was ‘something to worry about ... If the number of theorems is larger than one can possible survey, who can be trusted to judge what is “important”’;
• data was transmitted to earth from manned space flights at the rate of 52 kilobytes per second - the equivalent of the *Encyclopaedia Britannica* every 79 minutes;
• PhD’s in engineering have a ‘half-life’ of less than 10 years (i.e., only half of the information generated by the research is current after less than 10 years).

Examples like these are significant in several senses. For example, the explosion of information and data ‘makes control and regulation of intellectual property more difficult’ (Etzkowitz & Webster 1995, p. 492). Also, following Stanislaw’s concern about the proliferation of mathematical theorems, above, it has implications for developing scientific understanding, another use of knowledge in connection with science.

The rapid increase in available data is also related to the increasing availability and power of computing technologies:

> Computers are arguably among the half dozen most important post-World War II technologies, in impressive list that might include television, jet aircraft, satellites, missiles, atomic weapons, and genetic engineering. The proliferation of cheap, powerful information processing and computerised control systems has unquestionably altered - and in some cases deeply transformed - the nature of warfare, communication, science, offices, factories, government, and certain cultural forms. This point hardly requires substantiation; reportage on the ‘information revolution’ has become a virtual cottage industry. (Edwards 1995, p. 257)

Edwards notes that strong claims have been made for the impact of computing technology - revolutionary either for good (utopian) or evil (Orwellian) - which, although they reflect real hopes and concerns, respectively, have been overstated often:

> [R]evolutionary’ effects ... have been substantially, even hysterically oversold. This is especially true in the areas of office automation and computing in government, where their effects on productivity and panoptic power have been considerably less than many imagine. (Edwards 1995, p. 285)

In science, however, even allowing for some hyperbole, the effect of increasingly powerful computing technology has been a massive increase in the production of data, of the sort mentioned above. Some commentators further claim that computing technologies have changed the very nature of scientific research (Redner 1987)⁶. Such claims imply that the nature of scientific knowledge has changed as a result: that scientific knowledge is

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⁶ See the companion chapter on activity and Appendix B.5.
increasingly interdependent with the technology used to generate it, and the theories and assumptions built into the technology.

In any event, the explosion of scientific information clearly entails too great a volume and diversity of data and information to understand it all. We shall now turn to this sense of knowledge.
6.6 Knowledge and understanding

Sometimes knowledge is used with understanding: in several themes within the literature and in general use. Understanding usually means knowledge of the underlying argument or of the implications, and is therefore more complex:

When a person knows the answer to some question, but lacks the ability to explain why that should be the right answer, we commonly say that such a person knows the answer but does not understand it. (Tiles & Tiles 1993, p. 16; emphasis in original)

This follows Plato's requirement that knowledge is based on reasoning, not authority. Terms such as data and information are inadequate to convey this sense: no individual can hope to be familiar with their reasoned justification, and must accept their vast bulk on the basis of authority alone. In contrast, understanding does entail reasoned knowledge:

**Understanding:**
1. the act of one who understands; comprehension; personal interpretation.
2. intelligence; wit.
3. superior intelligence; superior power of recognising the truth: men of understanding.
4. a mutual comprehension of each other's meaning, thoughts, etc.
5. Philosophy: discursive knowledge based on premises and observations.

**Understand:**
1. to perceive the meaning of; grasp the idea of; comprehend.
2. to be thoroughly familiar with; apprehend clearly the character or nature of.
3. to comprehend by knowing the meaning of the words employed, as a language;
4. to interpret, or assign a meaning to; take to mean;
5. to grasp the significance, implications, or importance of.
11. to perceive what is meant.
15. to be informed; believe.

**Discursive:**
2. proceeding by reasoning or argument; not intuitive.

(The Macquarie Dictionary)

Scientific knowledge in the sense of the knowing individual clearly entails thorough familiarity and comprehension, and not the simple recall of facts, information or data. Understanding also has implications for scientific knowledge in the sense of an 'external' body of knowledge given in texts, because quite clearly scientific texts have to provide the argument to enable the personal understanding and comprehension. However, just as clearly, the mere existence of texts does not entail an individual having that scientific knowledge: simply, it is available.

The public understanding of science

Understanding and science are used together also in the sense of public understanding of scientific issues. Wynne (1995) has reviewed the literature on the public
understanding of science, which became an identifiable field from the 1980s. This literature tended to characterise scientific knowledges, practices and institutions as relatively unproblematic, and identified the public understanding (or misunderstanding) of this as the suitable problems to investigate:

In many dominant formulations (e.g. Royal Society 1985), public understanding of science is automatically equated with public appreciation and support of science, and with the public’s ‘correct’ understanding and use of ‘technical’ knowledge and advice. Thus, when publics resist or ignore a program advanced in the name of science, the cause is assumed to be their misunderstanding of the science. The public understanding of science research agenda is thus confined to measuring, explaining, and finding remedies for apparent shortfalls of ‘correct understanding and use’ as if this were free of framing commitments that have social implications. The field of risk perception research, for example, was defined by the assumption that the public opposed technologies like nuclear power because they misunderstood the ‘real’ risks as known to science; this view has resisted many substantive critiques (Otway 1992; Wynne 1992). (Wynne 1995, pp. 362-3)

However, as the literature developed, it identified a number of confusions and complications. For example, the term understanding in public understanding of science is used variously: to refer both to science-in-general and science-in-particular; to mean the effective use of technical knowledge, even though one may have understanding despite being unable to use this knowledge; to mean understanding scientific methods but not having specific knowledge content; and to mean understanding ‘its institutional characteristics, its forms of patronage and control, and its social implications’ (Wynne 1995, p. 363). The present thesis interprets these various meanings as having understanding of some dimensions - knowledge, activity, structure and context in these examples - but not all, and certainly not as they interrelate.

In recent times the focus of research in public understanding of science shifted from public misunderstandings of unproblematic science to public perception and interaction with constructed and negotiated science:

By contrast, critical research approaches informed by the sociology of scientific knowledge (SSK) - what I call here the constructivist perspective - have attempted to investigate how people experience and define ‘science’ in social life, and how particular scientific constructions incorporate tacit, closed models of social relationships that are or should be open to negotiation. In other words, scientific knowledge is seen as encoding taken-for-granted norms, commitments, and assumptions that, when deployed in public, inevitably take on a social-prescriptive role. Thus dominant internal criteria of ‘valid knowledge’ or ‘good science’ may be legitimately open to question when science is used in public arenas. (Wynne 1995, p. 362)

Thus this critical perspective addresses problems with science as well as with the public, and allows for more diverse and richer interactions between the two. Clearly, this perspective allows for, and encourages, richer characterisations of science such as proposed by the present thesis.
Wynne (1995, pp. 364ff) has identified three main conceptions of public understanding of science, arising from three main research approaches. Each approach brings its own insights, some of which we will mention. The first approach addresses public attitudes to science, scientific literacy and understanding of science, as measured by large-scale quantitative surveys. Wynne is critical of most of these surveys because they tend to assume a particular, uncritical, characterisation of science and ‘problematise’ the public:

Large-scale surveys of public attitudes towards and understandings of science inevitably build in certain normative assumptions about the public, about what is meant by science and scientific knowledge, and about understanding. They may often therefore reinforce the syndrome ... in which only the public, and not science or scientific culture and institutions, are problematised in the public understanding of science issue. Such surveys take the respondent out of social context and are intrinsically unable to examine or control analytically for the potentially variable, socially rooted meanings that key terms have for social actors. The survey method by its nature decontextualises knowledge and understanding and imposes the assumption that their meaning exists independently of human subjects interacting socially. Evidence of internal coherence among survey data is not itself evidence of wider validity - only of internal consistency. Too often the latter is mistaken for the former. (Wynne 1995, p. 370)

The second approach addresses ‘mental models’ of scientific processes, as measured by cognitive psychology tests. This approach studies the models by which people are thought to recognise patterns, make inferences and predictions, and so forth. Though not as clearly as for the large-scale surveys, this approach tends also to build in assumptions about ideal forms of reasoning and understanding. Models analysed in the literature include navigation, evaporation, global warming and motion; lay models are called naive theory in some studies, but others prefer folk theory as less prejudicial (Wynne 1995, p. 371). Ethnographic studies (or ethnoscientific research) argue that the mental models in folk theories are ‘more socially derived and situational’ rather than universal (Wynne 1995, p. 374). Folk theories are problematic for interpreting public understanding of science by traditional characterisations of science. Sometimes respondents give conflicting folk theories as explanations, but the one agreeing most with the accepted scientific explanation is not always the most useful. Also, traditional (positivist) characterisations present science as universal or independent of context, yet useful folk knowledge is frequently situational. Thus ethnoscientific, which includes feminist critiques of science, values the ‘rationality of ambivalence’ (Wynne 1995, pp. 374-5). This has strong implications for the science education of citizens, which we will pursue in chapter 12.

The third approach is to address the different experiences and constructions of science by people in different contexts, as measured (described) by qualitative anthropological field research:
This area of research shares a commitment to avoiding a priori assumptions about what 'proper' science is ... It attempts to examine the influence of social contexts and social relations upon people's renegotiation of the 'science' handed down from formal institutions as if already validated and closed. This general approach immediately opens to question the very notion of what counts as a scientific-technical issue or as scientific-technical knowledge. A common thread in all this research is the encounter of different cultures: on the one hand, scientific culture, which tends to reduce issues to those of control and prediction within the terms of the scientific field in play, and on the other hand, social worlds that reflect fundamentally different models of agency, and also recognise many more crosscutting and open-ended agendas and interests beyond those embedded in scientific discourse. (Wynne 1995, p. 375)

This approach includes research in several fields, including: sociology of medicine and public health; community responses to expert intervention, including technological accidents and emergencies; reproductive technologies and other women's studies; environmental controversies, campaigning and regulations; lay use of expertise, such as toxic waste chemistry, and lay constructs of 'deviant knowledge such as UFOlogy'; and anthropology of 'Third World' encounters with the culture of western European science (Wynne 1995, p. 375). In many of these studies, science as such may not be explicit, but becomes embedded in ordinary social and cultural practice. This general approach has profound implications for the public understanding of science, because it does not accept that scientific knowledge, as published in refereed scientific texts, is universal and unchanging; scientific knowledge that simply is endorsed as part of government policy or industry practice is even more contestable.
6.7 Knowledge/understanding as concepts and propositions

We have described scientific knowledge that is reasoned, or argued, as understanding. There are two further, related, senses of this understanding by which some of the literature characterises science. These are, first, the expression of understandings as statements, as mentioned above by Callon, and secondly, their cognitive status as concepts.

First, understandings of knowledge are expressed usually as statements called propositions:

*Proposition:*
4. a thing, matter, or person considered as something to be dealt with or encountered.
5. anything stated or affirmed for discussion or illustration.
6. Logic: a statement in which something (a predicate) is affirmed or denied of a subject, or in which membership of a class is affirmed or denied of something, or in which a relation is affirmed or denied to hold between two or more things. (*The Macquarie Dictionary*)

Thus the entries in Table B.6.2 are constructed as propositions or statements of knowledge, as in this example:

*Change in the cosmos has material, rather than supernatural, causes.*

In philosophy, propositional knowledge is given typically as statements with the form *that* $p$, where $p$ is a predicate that affirms or denies a claim. Thus, for example, the standard or tripartite definition of propositional knowledge, discussed above, holds that we have propositional knowledge when we have justified, true, belief *that* $p$. However, theories of propositional knowledge disagree whether a proposition picks out a propositional attitude necessary for knowledge (as in being sure *that* $p$, or believing *that* $p$), or whether a proposition *that* $p$ only serves to label a specific ability, capacity or power:

For instance, White (1982) treats propositional knowledge as merely the ability to provide a correct answer to a possible question. However, White may be equating ‘producing’ knowledge in the sense of producing ‘the correct answer to a possible question’ with ‘displaying’ knowledge in the sense of manifesting knowledge. The latter can be done even by very young children and some non-human animals independently of their being asked questions, understanding questions, or recognising answers to questions. (Shope 1993, p. 400).

That is, simply displaying or manifesting knowledge, as young children can do or indeed as typical quiz answers require, falls short of knowledge as understanding. That is, simply stating a single proposition, such as

*Light bends as it passes from air through a glass prism*

does not demonstrate understanding. Nevertheless, science knowledge—that is propositional knowledge: it is structured as propositions.
The second sense is knowledge as a notion or concept, where a concept is the generalised term for a number of entities that are similar in some way:

**Concept:**
1. a thought, idea, or notion, often one deriving from a generalising mental operation.
2. a theoretical construct: a concept of the solar system.
3. an idea that includes all that is associated with a word or other symbol.
4. an idea elaborated into a pattern or procedure: a new concept in roof maintenance.
5. a design in which all aspects of the product are linked to a central idea, function, theory, etc.  
   *(The Macquarie Dictionary)*

More particularly, a concept refers to knowledge content:

Mental states have contents: a belief may have the content that I will catch the train, a hope may have the content that the prime minister will resign. A concept is something which is capable of being a constituent of such contents. More specifically, a concept is a way of thinking of something - a particular object, or property, or relation, or some other entity. *(Peacocke 1993, p. 74)*

Thus a concept concerns knowledge, and in philosophy is described by epistemology; it is not equivalent to its content, which in philosophy is described by metaphysics and ontology. We will return to knowledge content in section 6.10, below.

Peacocke (1993) makes some useful distinctions concerning concepts, which we shall mention here. First, different concepts may be different ways of thinking about the same object: for example, at the one time an adult person may be thought of as a citizen, spouse, parent, worker and driver. Secondly, when concepts are expressed in a proposition that p, ‘they will be capable of being true or false, depending on the way the world is’ *(Peacocke 1993, p. 74)*. Thirdly, concepts are not stereotypes: we can believe that Stephen Hawking falls under the concept scientist, for example, while disbelieving he falls under the stereotype of the white-coated man tending elaborate chemical glassware. Fourthly, the statement by which we express the meaning (content) of a concept is taken usually as the means by which we differentiate concepts from each other. Fifthly, the way we make meaning of concepts can be complex. Our mastery of a concept is helped when we find it compelling to use that concept, an insight of the later Wittgenstein. Related to this, we sometimes determine the meanings of groups or clusters of concepts simultaneously: for example belief and desire can identify a combined mental state. Sixthly, some accounts emphasise ‘the links between a concept and the thinker’s perceptual experience’ *(Peacocke 1993, p. 75)*; concepts may thus vary with different environmental circumstances. Some accounts extend this to argue that the conceptual content of one’s mental state varies with variation in the social environment, especially with linguistic relations. For example, Knorr Cetina (1995, p. 141) has cited several studies that show ‘how the beliefs and knowledge claims of scientists are influenced by their social context’.
Some accounts link concepts, understandings and propositions, on the basis that the expression of the conceptual content as a statement expresses an understanding that is propositional knowledge. This view emphasises knowledge as a condition of the knower, and is evident particularly in the psychology of learning (Gagné 1970; Gagné & Driscoll 1988; White & Gunstone 1992). For example, Gagné and Driscoll (1988, pp. 47ff) have argued that an important category of learning outcomes is intellectual skills, which are a type of knowing how, rather than information or knowledge-that. Concept-formation is the construction of categories that free the learner from learning multiple individual instances:

It would not be possible to learn all these things as verbal information, or as facts, because too many individual instances exist. The intellectual skill you learn enable you to respond adequately to entire classes (that is, groups or categories) of interactions with the environment through symbols, such as letters, numbers, words, or diagrams. (Gagné & Driscoll 1988, p. 47)

Gagné and Driscoll rank these skills in a hierarchy, from simple types of learning, to discriminations, concrete concepts, defined concepts, rules and higher-order rules. The higher, more complex types require the prior learning of the simpler ones. Thus discriminations, which entail telling the difference between stimuli, are necessary to cluster or group features, objects or events that are similar: that is, to form concrete concepts. Concrete concepts may be: objects, such as tree, dog or rock; the qualities of objects, such as colour, pointed or smooth; or relations, such as up, down, higher or near. Concepts may also be defined rather than concrete, such as obstacle, uncle or buyer. There is a sense in which both of Gagné and Driscoll's conceptual categories, concrete and defined, are both defined, since the meanings of terms in both groups are agreed or defined by convention. It would seem that the category concrete refers to concepts with observable characteristics, and defined refers to those without observable characteristics. Both types of concept may apply to the one word: for example, flower in poetry remains a concrete concept, but in science it is by definition an organ of a plant associated with sexual reproduction.

Part of the precision of science knowledge arises from this type of concept that defines classes of entities. Concepts are used in rules for activities, such as,

Classify examples of flowers.

In turn simple rules are used in higher-order rules such as,

Generate a scheme for classifying flowers.

The conceptual complexity of recent and current science

A final point in this section is that science knowledge is conceptually complex, and has become increasingly so during the twentieth century. There are many well known examples, and in many fields, such as physics (quantum mechanics and relativity theory),
chemistry (developments of new materials such as ceramics, plastics and fullerenes) and biology (the human genome project). Wolpert (1992) has argued that science knowledge is counter-intuitive, in part due to its conceptual complexity:

The central theme presented in this book is that many of the misunderstandings about the nature of science might be corrected once it is realised just how 'unnatural' science is. I will argue that science involves a special mode of thought and is unnatural for two main reasons ... Firstly, the world is not constructed on a common-sensical basis. This means that 'natural' thinking - ordinary, day-to-day common sense - will never give an understanding about the nature of science. Scientific ideas are, with rare exceptions, counter-intuitive: they cannot be acquired by simple inspection of phenomena and are often outside everyday experience. Secondly, doing science requires a conscious awareness of the pitfalls of 'natural' thinking. For common sense is prone to error when applied to problems requiring rigorous and quantitative thinking; lay theories are highly unreliable. (Wolpert 1992, pp. xi-xii)

Wolpert's analysis makes a valid point that scientific knowledge is complex and increasingly difficult, particularly for lay audiences. However, it seems remarkably naive: it uncritically presents views that have been subject to telling criticism in both post-positivist HPS and STS. Also, its basic premise overlooks the fundamental point that much of science is commonsensical, as claimed in summary statements 17 and 49; rather, the success of science has been to enable us to develop counter-intuitive understandings as well. That is, science knowledge is not limited to the common-sensical, and as science knowledge has become increasingly complex and abstract, it moves beyond what is common-sensical to lay audiences.

6.8 Knowledge and power

This section addresses several ways in which scientific knowledge is characterised by power and usefulness, usually as its ability to predict. The companion chapter on context mentions the historical association, usually dating from Francis Bacon, between knowledge and power7. This association is the basis for two commonly held assumptions about scientific knowledge, namely that western European science is the paradigm of rational knowledge, and that this accounts for the power of western societies:

By and large, past cross-cultural work has taken Western 'rationality' and 'scientificity' as the bench mark criteria by which other cultures' knowledges should be evaluated. So-called traditional knowledge systems of indigenous peoples have frequently been portrayed as closed, pragmatic, utilitarian, value laden, indexical, context dependent, and so on, implying that they cannot have the same authority and credibility as science because their localness restricts them to the social and cultural circumstances of the production. These were accounts of dichotomy where the great divide between societies that are powerful and those that are not. Here was a satisfying explanation of the relation between knowledge and power. (Watson-Verran & Turnbull 1995, pp. 115-6)
As argued in Appendix B.1 on context, this view dominated until the second half of the twentieth century because of the positivist RV, which allowed only empirical and rationally reconstructed knowledge—that as the scientific norm. In this view, the power of scientific knowledge is self-evident in its successful technological application, arising from its empirical and rational character.

However, in post-positivist studies of science, the association between knowledge and power is not so clear, and there is a tension between competing views (Watson-Verran & Turnbull 1995). On the one hand (western European) science knowledge is undoubtedly successful in sustaining predictions. On the other there is no agreed account of why this knowledge should be so powerful, especially if only the cognitive context is considered; further, attempts to portray western European science as the standard for rationality ignore the predictive successes (power) of some other knowledge systems.

This opposition of views is significant, and relates a number of issues raised in other companion chapters. First, the RV does not hold up to telling criticisms. For example, as argued in the companion chapter on activity and Appendix B.5, the normative RV does not account for the actual activities of scientists; therefore, it does not account for the successes of science. Further, particular activities such as observation, induction, verification and falsification do not withstand the rational reconstruction required by the RV. Secondly, the RV denies the demonstrable power and authority of other knowledge systems. For example, some indigenous knowledge systems have enabled remarkable feats of navigation, construction and transformation of materials, yet they are tacit and localised, and not rationally reconstructed. Thirdly, western European science has undoubted successes and strengths, that a strong relativism fails to identify. Despite the absence of an agreed, rational explanation of scientific activities, such as induction or indeed of agreed criteria of rationality, scientists collect observational data inductively because it continues to be a source of successful predictions. In this way a body of knowledge develops that is powerful because it sustains predictions. Thus the link between science knowledge and power is qualified.

Post-positivist accounts tend to imply a more complex association between knowledge and power than the positivist RV allowed. These views no longer see the power or utility of scientific knowledge arising uniquely from its cognitive character. The present thesis interprets this as the effect of multiple dimensions in combination: scientific knowledge develops according to particular beliefs, purposes, contexts and so on. This implies decisions leading to and arising from scientific knowledge:

We have unparalleled knowledge and power over nature, yet this faces us with moral dilemmas and responsibilities for which we are ill-prepared. We can if we choose keep alive the victims of brain damage, or cruelly deformed children who

---

8 This is discussed at greater length in Appendices B.1 and B.2 on context and belief system respectively.
once would have died: reason and humanity are both confused by such choices, and the exercise of the power we have attained, in either direction, leaves us tainted. Our technology has made it easy for us to burn up in a few decades the oil produced in many millions of years, or to destroy the last forests, or drive to extinction an increasing range of living creatures ...

In many ways we have the feeling of living at the end of an era, rather than the beginning of a new one. Both those who are optimistic about the future and those who are pessimistic agree in predicting rapid change. Few believe that the world in 20 years' time will be very similar to the world as it is today, yet the feeling is of moving away from what we have, rather than moving toward a welcoming future.

The Victorian [era response to the Industrial Revolution] led toward the danger of complacency. Our own offers a choice of two: on the one hand, despondency, and on the other, a millennial optimism, both of which can be seen at the present time. (Rosenbrock et al [sic] 1981)

While all but an extreme externalism claim at least a partly cognitive (internal) character for scientific knowledge, notions like power cannot be strictly internalist. Thus the equation between knowledge and power is characterised by knowledge and other dimensions, such as context, purpose and belief system. For example, there is an increasing tendency for scientific knowledge to be expressed in patents, and to be considered as intellectual property that can be bartered. Thus knowledge becomes a kind of currency that cannot be described adequately by its cognitive characteristics alone. Rosenbrock makes a strong appeal to values and other elements of belief system that strongly challenges the notion of science knowledge as value-neutral.

6.9 Knowledge as a map of scientific content; current scientific knowledge

Scientific knowledge in the twentieth century has increased and diversified rapidly: the notion of the information explosion summarises this characteristic of current scientific knowledge well. As a consequence, mapping the current state of scientific knowledge content is difficult, especially in fields at the vanguard such as microbiology or genetic engineering. Any attempt to list the content of science knowledge would be implausible and, even is possible, too big to suit the purpose of the present thesis. The detail of current knowledge in particular fields is in any case the main content of science text books. Instead, our purpose here is to show how knowledge content partly characterises science.

The content of scientific knowledge is taken to be the semantic content - the meaning - of knowledge propositions in science, and the framework of concepts they embody. Thus Heilbron (1983c) has characterised the development of twentieth century physics by changes in the concepts that were fundamental at the turn of the century. He characterises physics circa 1900 by the major concepts electricity and magnetism, heat and thermodynamics, hydrodynamics and hydrostatics, light and mechanics. He gives the major concepts of 20th century physics as atomic structure, elementary particle, nucleus, quantum, radioactivity and relativity. In discussing the new physics, Heilbron
Appendix B.6: Knowledge

distinguishes between concepts that are not carried forward because they have been superseded or are no longer central, and those that are not carried forward because they remain current but no longer excite attention.

The character of science knowledge content depends on the perspective taken for analysis. One perspective is that the content of science knowledge characteristically concerns the material world or the cosmos: animals, plants, forces, chemicals, planets, and so forth. They are recognisably scientific concepts, rather than economic, aesthetic or historical ones, for example. However, this distinction leads to problems; it is simplistic and does not address other distinctions. One example is the distinction between the natural and made worlds, which arises from a narrower characterisation of science as concerning Nature only: at what point does the content of chemistry or genetics cease to be Nature and instead becomes the product of earlier science? This distinction does not arise in broader characterisations of science. Another is the distinction between science and non-science: astronomy and astrology, for example, or evolution and Creation Science. (These are examples of boundary work, as discussed in the companion chapter on context and Appendix B.1.) Each of these choices shares some concepts that most commentators would agree are characteristically scientific: celestial phenomena in astronomy and astrology, and variation in living things in evolution and Creation Science. However, their status as science is different, and science knowledge alone does not account for this. The present thesis argues that knowledge content alone, while a necessary dimension, is insufficient, and these difficulties can be addressed by recognising that scientific knowledge is characterised also by its particular contextual influences, structures, purposes, activities and particular beliefs and value preferences, as argued in the companion chapters as a set. The present section focuses on the knowledge itself.

Another characterisation of science knowledge content is by fields, domains or disciplines of science in the sense of intellectual or cognitive structures: the name of the field is the overarching concept that is central to a framework of interrelated concepts. General dictionaries of science provide a summary of such concepts. For example, the entries in *The Macmillan Dictionary of the History of Science* (Bynum, Browne and Porter (eds) 1983) are listed alphabetically by concept, but also near the front as lists by field: Astronomy, Biology (with a note to see Human Sciences and Medicine), Chemistry, Earth Sciences, Historiography and Sociology of Science, Human Sciences, Mathematics, Medicine (with a note to see also Human Sciences, Biology and Chemistry), Miscellaneous, Philosophy of Science, and Physics (with a note to see also Astronomy, Chemistry, Mathematics and Philosophy).

A third characterisation of science knowledge content, particularly its currency, is by its published source. Changes in science knowledge are more pronounced at the level of particular understandings; the more general the knowledge proposition or concept, the
Appendix B.6: Knowledge

less subject it is to change. This is reflected in the publication of scientific knowledge. Typically the current state of knowledge is to be found in journals. Many of these are very specialised and are difficult to understand for a lay audience, which increasingly includes scientists from other specialisations. In at least some rapidly developing fields it is not even the journals that contain the latest developments, but informal networks of scientists: to be up to date requires being part of the right networks. Text books on specific topics are generally not as current as journal articles, and general science texts cover well-established, and therefore older, content again. Currency of ideas is traded against some measure of the significance and place of knowledge; as a rule, the more general the text, the more general, established and enduring, but less current, its content.

Consequently, the current state of scientific knowledge is difficult to summarise meaningfully. There are so many developments, in so many scientific fields, that it is difficult to keep track of them all, and impossible to develop a reasoned understanding of them all. We have also mentioned that scientific concepts are increasingly complex. In any event, the very nature of science knowledge means that the mere announcement of a breakthrough is not sufficient, and we need to await replications of experiments and theoretical critiques to avoid placing too much credence on fresh claims. This makes it very difficult to characterise the current state of science knowledge, except perhaps in general terms.

One indication is the *Dissertation Abstracts International*, given in Table B.4.2. Another is to review science journals, or journals that review science journals. In a publication sense, journals and abstracts remain current only for the period of publication, usually a week, month or quarter; whether the content of older publications is still current has to be judged by those who are regular readers and would know if content has been updated later. As an example of recent coverage of science knowledge content, Table B.6.4 sets out the cover page by-lines for *Nature* and *New Scientist*, for the month June 1996. These journals were selected simply because they are authoritative, widely known and available journals that review science developments generally; that is, they are not restricted to particular science subjects, like, say, a physics journal. Additionally, *New Scientist* includes a segment each week, called *Science*, that reviews new scientific developments and claims; Table B.6.4 includes the by-lines for these entries also. The wording in Table B.6.4 is not always verbatim, to compensate for the creativity of the sub-editors: the intention is to indicate the range of topics contained in these updates. Note that only some developments are reported by both journals.

In summary, the content of science knowledge is characterised by an astounding diversity and growth. At the level of particular propositions of knowledge—that science knowledge is tentative, but only in the sense that it is in principle revisable or contestable. Most metascientific accounts, and indeed most public characterisations of science, do not regard science knowledge as tentative in the sense of ephemeral or transient. The present
thesis argues that the literature makes this distinction by characterising science knowledge partly by particular activities, purposes, contexts, structures and belief systems, including criteria for making judgements. Knowledge content is less subject to change at the level of concepts, which are generalising cognitive terms.
### Table B.6.1

Examples of characterisation of key metascientific viewpoints by knowledge

<table>
<thead>
<tr>
<th>Author</th>
<th>Viewpoint</th>
<th>Examples of reference to knowledge</th>
<th>Identified in the work of ...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suppe 1973, 1979</td>
<td>Received View</td>
<td>Knowledge can be represented as a logical, related, system of theoretical concepts and conclusions</td>
<td>Carnap; the Vienna Circle</td>
</tr>
<tr>
<td></td>
<td>sceptical descriptive</td>
<td>Theories are systems of propositions, but have no other generalised characteristics.</td>
<td>Achinstein, Rapoport</td>
</tr>
<tr>
<td></td>
<td>Weltanschauungen (world view)</td>
<td>Scientific knowledge is not acontextual, but instead is meaningful only within a Weltanschauungen.</td>
<td>Bohm, Feyerabend, Hanson, Kuhn, Popper, Toulmin</td>
</tr>
<tr>
<td></td>
<td>semantic or model-theory</td>
<td>Scientific knowledge is given in the language of theories.</td>
<td>Beth, Suppe, Suppes, van Fraasen</td>
</tr>
<tr>
<td></td>
<td>historical realism</td>
<td>Scientific knowledge arises from the reasoning by which theories are developed as well as from experimental data.</td>
<td>Lakatos, Shapere, Toulmin</td>
</tr>
<tr>
<td>Bhaskar 1983</td>
<td>empiricism</td>
<td>Knowledge is given in experience.</td>
<td>Francis Bacon, Berkeley, Hobbes, Hume, Locke, Mach (positivism), Mill, Russell, Vienna Circle (logical empiricism)</td>
</tr>
<tr>
<td></td>
<td>idealism</td>
<td>Knowledge is what we make or construct.</td>
<td>Berkeley, Fichte, Hegel, Hume, Kant, Plato, Schelling</td>
</tr>
<tr>
<td></td>
<td>realism</td>
<td>Knowledge is constructed but given in an external reality.</td>
<td>Aristotle, Bachelard, Bhaskar, Duhem, Feyerabend, Hanson, Harré, Hesse, Hume, Kant, Koyré, Kuhn, Plato, Popper, Putnam, Quine</td>
</tr>
<tr>
<td>Nussbaum 1989</td>
<td>rationalism</td>
<td>Proven or confirmed knowledge is primarily acquired by the power of the intellect.</td>
<td>Descartes, Kant, Plato</td>
</tr>
<tr>
<td></td>
<td>empiricism/positivism</td>
<td>Proven or confirmed knowledge is primarily acquired by the evidence of the senses.</td>
<td>Bacon, Comte, Hempel, Hume, Locke</td>
</tr>
<tr>
<td></td>
<td>constructivism</td>
<td>The best current knowledge is acquired according to (a) inner disciplinary criteria (rational, logical, empirical) (b) outer disciplinary criteria (social-psychological, historical).</td>
<td>(a) Popper, Lakatos, Toulmin, partly Kuhn (b) Kuhn, Toulmin, partly Lakatos</td>
</tr>
<tr>
<td>Boyd, Gaspar and Trout 1991</td>
<td>post-positivist consensus comprising (a) post-positivist empiricism, (b) neo-Kantian constructivism and (c) scientific realism</td>
<td>The definitions of scientific concepts and terms are theory-dependent.</td>
<td>(a) Partly Popper (b) Hanson, Kuhn (c) Boyd, Goodman, Kripke, Putnam, Quine</td>
</tr>
<tr>
<td>Pickering 1992</td>
<td>scientific knowledge as objective (logical empiricism)</td>
<td>Science knowledge arises objectively from empirical inquiry.</td>
<td>As given by Suppe</td>
</tr>
<tr>
<td>Callon 1995</td>
<td>scientific knowledge as relative to culture</td>
<td>Scientific knowledge arises within various cultural contexts.</td>
<td>Kuhn, Feyerabend</td>
</tr>
<tr>
<td></td>
<td>scientific knowledge as relative to interests (sociology of scientific knowledge - SSK)</td>
<td>Scientific concepts at different levels of abstraction are linked together by generalisations and to the natural world by instances grouped under observation terms. 'New scientific knowledge entails seeing new situations as being relevantly like old ones.' (p. 4)</td>
<td>Barnes, Bloor, Callon, Cartwright, Collins, Garfinkel, Gilbert, Knorr Cetina, Latour, Law, Lynch, Mulkay, Shapin, Woolgar</td>
</tr>
<tr>
<td></td>
<td>science as rational knowledge</td>
<td>Science knowledge is given in statements, usually distinguished as observational / empirical (of experiments and data collection) and theoretical statements (of conjectures and generalisations. Model 2 applies here.</td>
<td>Hesse, Holton, Popper</td>
</tr>
<tr>
<td></td>
<td>science as competitive enterprise</td>
<td>Science knowledge is given as theoretical statements that are evaluated by a competitive process.</td>
<td>Althusser, Ben-Cole, David, Freudenthal, Hull, Merton, Popper</td>
</tr>
<tr>
<td></td>
<td>science as sociocultural practice</td>
<td>Statements are meaningless without context; science knowledge is partly nonpropositional (tacit knowledge).</td>
<td>Bachelard, Barnes, Collins, Fleck, Knorr, Kuhn, Mulkay, Pinch, Ravetz, Rudwick, Schaffer, Wise, Wittgenstein</td>
</tr>
<tr>
<td></td>
<td>science as extended translation</td>
<td>Knowledge is produced by temporarily stabilised networks of actants.</td>
<td>Amaan, Callon, Foucault, Knorr Cetina, Latour, Pickering, Wise, Woolgar</td>
</tr>
</tbody>
</table>
# Table B.6.2

## A Chronology of Contributions to Science Knowledge Propositions

(from Bynum, Browne & Porter 1983)

<table>
<thead>
<tr>
<th>Dates</th>
<th>Name</th>
<th>Nationality</th>
<th>Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>c 624-546 BC</td>
<td>Thales of Miletus</td>
<td>Greek</td>
<td>Change in the cosmos has material, rather than supernatural, causes.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Water is the basic element from which all parts of the cosmos are made.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Nature is made more comprehensible by the reduction of theories into fewer, simpler and more powerful frameworks.</td>
</tr>
<tr>
<td>c 552-479 BC</td>
<td>Confucius and followers of his philosophy</td>
<td>Chinese</td>
<td>The five Phases or Elements are Metal, Wood, Water, Fire and Earth.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Natural numbers (2,3,5,6,8,12...) have hidden meanings (such as yin/yang pairs, eg, maleness and femaleness).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Strings vibrating in octaves, fifths and fourths have lengths in numerical ratios.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Natural numbers (1,2,3...) have hidden meanings (such as maleness and femaleness).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>The fundamental types of knowledge are geometry, arithmetic and music.</td>
</tr>
<tr>
<td>c 560-c 480 BC</td>
<td>Pythagoras</td>
<td>Greek</td>
<td>Nature is made more comprehensible by the reduction of theories into fewer, simpler and more powerful frameworks.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Strings vibrating in octaves, fifths and fourths have lengths in numerical ratios.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Natural numbers (1,2,3...) have hidden meanings (such as maleness and femaleness).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>The fundamental types of knowledge are geometry, arithmetic and music.</td>
</tr>
<tr>
<td>540-475 BC</td>
<td>Heraclitus</td>
<td>Greek</td>
<td>The cosmos is in a state of constant change from the interplay of opposites.</td>
</tr>
<tr>
<td>c 515-c 450 BC</td>
<td>Parmenides</td>
<td>Greek</td>
<td>The cosmos is essentially unchangeable, not in a state of constant change.</td>
</tr>
<tr>
<td>fl c 500 BC</td>
<td>Alcmaeon of Crotona</td>
<td>Italian-Greek</td>
<td>Dissection is a means of demonstrating structure and function, eg, dissection of the eye shows the channels linking the eye and brain.</td>
</tr>
<tr>
<td>c 500-c 428 BC</td>
<td>Anaxagoras</td>
<td>Greek</td>
<td>Substances are continuous (ie, can be divided infinitely).</td>
</tr>
<tr>
<td>c 492-432 BC</td>
<td>Empedocles</td>
<td>Sicilian</td>
<td>Substances are continuous (ie, can be divided infinitely).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fire, earth, air (or pneuma or spirit) and water are the four elements from which the world is made, and each tends to its natural place.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Heat results from the presence of fire in a substance.</td>
</tr>
<tr>
<td>c 490-430 BC</td>
<td>Zeno of Elea</td>
<td>Greek</td>
<td>A technique for refuting hypotheses is to draw unacceptable conclusions from them, such as paradoxes, as in dialectic technique.</td>
</tr>
<tr>
<td>c 470-399 BC</td>
<td>Socrates</td>
<td>Greek</td>
<td>The method of refuting the hypothesis of an opponent by drawing unacceptable conclusions is called a dialectic. Such argument is for the purpose of the disinterested pursuit of truth, not victory in debate.</td>
</tr>
<tr>
<td>c 460-371 BC</td>
<td>Democritus</td>
<td>Greek</td>
<td>Substances cannot be divided infinitely (ie, matter is not continuous) because matter is made from homogeneous entities (called &quot;atoms&quot;) that are eternal, unchanging and indivisible.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Atoms are identical in their makeup but differ in their geometrical and mechanical properties.</td>
</tr>
<tr>
<td>c 450-c 370 BC</td>
<td>Hippocrates of Cos</td>
<td>Greek</td>
<td>The patient is an individual with his/her own disease.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Disease is caused by an imbalance of humours, not by magic or gods.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Diagnosis should consider the whole person and precede by logically dividing the possibilities.</td>
</tr>
</tbody>
</table>
5th-4th cent. BC Followers of Hippocrates

Inflammation and other conditions which result from an excess of the humour blood should be treated by blood letting.

Epilepsy is an ordinary disease, of the brain, and therefore to be treated by diet and drugs, not prayers and incantations.

The role of the doctor is to help rather than confront Nature, because the body has inherent, natural, powers for restoring its health.

Disease in general is not distinct from the person afflicted with the disease

There is a continuum between health and disease.

Disease is a disturbance from a healthy balance.

The healthy balance is restored by using remedies which oppose the disease, eg., cold against hot, i.e., treatment is by opposites.

Moderation is therefore the key to health.

Prevention is preferred to cure.

Medicine is generally concerned with the health of the individual rather than with public health.

"All possible kinds of things exist."

The changing world apparent to our senses is made from more permanent and simpler forms called "elements".

Knowledge is different from mere belief.

Reason, not observation or experience, is the source of true knowledge.

Physics is better understood through geometry and contemplation of the ideal.

Atoms do not exist because there cannot be a vacuum or self-moving bodies.

The humours influence psychological behaviour.

Rules of conduct can affect individual health (hygiene).

The observable particulars of the world are copies of forms or Ideas which are not material but are also not mental, i.e., reality is ideas, not objects.

The soul comprises three parts (reason, spirit and appetite), is immortal and can remember its previous existence. Thought comes from the part of the soul in the head. Sensations come from the rational soul in the chest. Desires come from the appetitive soul in the liver.

Madness is a mental disorder.

Just as humans have a soul, so must the world. Just as humans are physically dependent on the world, so must they be spiritually dependent.

Curved geometrical shapes can be analysed using the method of exhaustion.

The motion of the planets is accounted for mathematically by the motion of four concentric spheres.

427-347 BC Plato Greek

The changing world apparent to our senses is made from more permanent and simpler forms called "elements".

Knowledge is different from mere belief.

Reason, not observation or experience, is the source of true knowledge.

Physics is better understood through geometry and contemplation of the ideal.

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Curved geometrical shapes can be analysed using the method of exhaustion.

The motion of the planets is accounted for mathematically by the motion of four concentric spheres.

c 400-347 BC Eudoxus of Greek Cnidus
The three fundamental types of knowledge are the theoretical sciences (physics, philosophy), the practical sciences (ethics, politics) and the poetic sciences (aesthetics).

There is no infinity (infinitely large, small or numerous), merely a potential for infinity.

Light passes from observed to observer.

Colour arises from the darkening of light by bodies in the medium.

The sublunary region is imperfect and is made of the four Elements, earth, fire, air and water.

The Elements can be changed into each other by exchange of their qualities (dry-cold, hot-dry, moist-hot, cold-moist respectively).

The qualities of the elements are the irreducible features of the appearance or behaviour of the elements.

Hotness, dryness, coldness and moistness define the four elements and, because they are manifest to the senses, are called the 'manifest' qualities.

Other qualities, like gravity, levity are hidden to the senses, and are called the 'occult' qualities.

The manifest and occult qualities are both accessible by reason, and are agents of motion.

Minerals and metals are formed deep in the Earth by the mingling of the dry and moist qualities of the Elements.

The earthly elements move in a linear, discontinuous manner.

The heavenly bodies move in a circular, continuous manner.

The celestial region includes a fifth element, the aether.

The source of all motion in the Universe is the prime mover, which moves the heavenly bodies, like humans are moved by the Good. In turn, the heavenly bodies are the source of movement in the sublunary region.

The eternal, most good mover is God.

The observed diurnal and independent motion of the planets is accounted for by a system of fifty five homocentric spheres.

Gravity is an occult quality located in the gravitating body, which tend towards the centre of the Universe.

Gravity is only found in substances below the sphere of the moon, and even then not in all, eg, fire, which levitates.

By means of dissection, it is possible to arrange animals hierarchically and to observe similarities between species.

Only the male parent determines the form of the offspring.

Atoms do not exist because there cannot be a vacuum or self-moving bodies.

There is wide diversity and complexity of plants.

Matter is ultimately composed of discrete particles, atoms, which can sometimes swerve from no external cause. This helps to explain free will in humans.

Body and soul differ in the combination of the same atomic units, not in substance.

Sense perceptions are reliable, contrary to Plato's claim, in that the eye takes in minute copies of objects radiated by them.

Hippocratic diagnosis can be used to good effect.
Appendix B.6: Knowledge

<table>
<thead>
<tr>
<th>Time</th>
<th>Author</th>
<th>Location</th>
<th>Facts</th>
</tr>
</thead>
<tbody>
<tr>
<td>fl c 290 BC</td>
<td>Herophilus</td>
<td>Alexandrian</td>
<td>Dissection and vivisection are methods of inquiry suitable for determining anatomy, including that of humans. The blood vessels comprise arteries and veins. The heart comprises a series of chambers and valves. Blood carries nourishment from the liver. The left ventricle and arteries carry only pneuma, holding blood only when the artery is cut because Nature abhors a vacuum. Nerves are confirmed by dissection as channels between the brain and sense organs. As for Herophilus. Digestion is a mechanical process, not the conversion by heat into chyle, then the humours.</td>
</tr>
<tr>
<td>fl c 280 BC</td>
<td>Erasistratus</td>
<td>Greek</td>
<td>Euclid Greek The known geometry can be organised as axioms (used in both Greek and Islamic science traditions). Light travels in straight lines, which can be described geometrically. There is an infinite amount of prime numbers. Vision works by the eye sending out invisible rays (pneuma) to form an impression of objects. Calibrated sighting instruments, such the astrolabe, quadrant and armillary sphere enable measured astronomical observations. The positions of the equinoxes move relative to the fixed stars.</td>
</tr>
<tr>
<td>d. after 127 BC</td>
<td>Hipparchus</td>
<td>Greek</td>
<td></td>
</tr>
<tr>
<td>fl 1st cent. BC</td>
<td>Vitruvius</td>
<td>Roman</td>
<td>Sound comprises vibrations or compressions. Reverberation and interference can arise in auditoria. Man is subject to the same natural law as the rest of Nature. Matter is composed of discrete particles, or atoms.</td>
</tr>
<tr>
<td>c 95-55 BC</td>
<td>Lucretius</td>
<td>Roman</td>
<td></td>
</tr>
<tr>
<td>20 BC-AD 50</td>
<td>Philo Judaeus</td>
<td>Alexandrian</td>
<td>Man and the cosmos are equally made of a mixture of the four elements. There are some numerological correspondences between man and the cosmos, such as the stars.</td>
</tr>
<tr>
<td>c 23-79 AD</td>
<td>Pliny the Elder</td>
<td>Roman</td>
<td>Components of tar can be separated by distillation. Volcanoes can be better understood through observation.</td>
</tr>
<tr>
<td>fl c 62 AD</td>
<td>Hero of Alexandria</td>
<td>Alexandrian</td>
<td>Sound comprises vibrations or compressions.</td>
</tr>
<tr>
<td>c 100-170 AD</td>
<td>Ptolemy, C.</td>
<td>Egyptian</td>
<td>The Egyptian calendar of 1 year=365 days is useful in making astronomical calculations. Aristotelian physics shows that the Earth is at rest. Geometry shows that the Earth is the centre of the Universe and that the stars move together as a sphere. Aristotelian physics shows that celestial motion, which is regular, is circular. Astronomical calculations must conform to mathematics rather than observations. The behaviour of light rays can be described geometrically. The planets orbit the Earth in a series of epicycles. The angle of light reflection equals its angle of incidence. Experiment shows a relationship between the angle of refraction and the medium of refraction. Light passes from observer to observed. Navigational position can be defined using a system of coordinates comprising parallels and meridians. The zero symbol can be used in expressing sexagesimal fractions. Calibrated sighting instruments, such the astrolabe, quadrant and armillary sphere enable measured astronomical observations.</td>
</tr>
</tbody>
</table>
Appendix B.6: Knowledge

129-c 200 AD Galen of Graeco-Roman

The practical medicine of the Hippocratics (4th-5th cent. BC) can be combined with Plato's idealist philosophy by means of Aristotle's logic.

Anatomy can be integrated with Hippocratic theories of humours.

There are structural similarities between humans and other animals.

The cranial nerves can be classified.

The control of food and drink affects health and the control of disease.

Disease is mainly the result of imbalance between the four humours, bile, phlegm, blood and black bile or "melancholy".

As advocated by the Hippocratics, and contrary to Erasistratus, food is converted by heat into chyle, then into the four humours, then into the body.

Dissection is a useful technique, despite being illegal.

Medical knowledge is advanced by experiment.

Bodily organs require a combination of humours (factors) to work normally and without which their working is impaired.

The three main faculties are genesis, growth and nutrition.

Purpose is reflected in function, i.e., form or structure is related to physiological function.

The three main organs are the heart, brain and the liver.

The body is kept alive by the heart.

The heat is nourished by the blood and ventilated by the lungs.

The innate heat in the heart promotes coction in the stomach, whereby food is converted into chyle.

Good health is always susceptible to changes from the non-naturals.

There are six necessary causes of health and disease: the air; food and drink; inanition; repletion; motion and rest; sleep and waking.

Disease can be treated by diet and drugs.

Drug mixtures are calibrated with the disease.

The crystalline humour is the sensitive part of the eye.

Magnetic compasses used in China 1000 years before Europe.

965-c 1040 Al-Haytham (Alhazen) Egyptian

Intromission (the movement of light from observed to observer, favoured by Aristotle) is a superior explanation to extromission (the movement of light from observer to observed, favoured by Euclid and Ptolemy).

Reflection from a curved surface can be calculated.

Refraction can be estimated.

The camera obscura and formation of images through pin holes can be explained.

The physics of light is related to the brain.

Sensation (of the image) is separate from perception (the interpretation by the brain).

Binocular fusion occurs in the common nerve (optic chiasma).

The image is inverted by the lens yet is perceived as upright.

The image corresponds to the object.

The dry and moist exhalations identified by Aristotle as the basis for minerals and metals are the Principles of Sulfur and Mercury, i.e., all the known metals are made from these two Principles.

Nest building by birds differs from human behaviour because it is invariable.

980-1037 Avicenna Persian
<table>
<thead>
<tr>
<th>Date</th>
<th>Name</th>
<th>Nationality</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>c 1250-1310</td>
<td>Theodoric, D.</td>
<td>German</td>
<td>Light and colour can be better understood through experiment.</td>
</tr>
<tr>
<td>c 1266-1308</td>
<td>Scotus, J.</td>
<td>British</td>
<td>Knowledge of the material world can be gained by the method of experimental agreement.</td>
</tr>
</tbody>
</table>
| fl c 1269  | Peregrinus, P.      | French      | The magnetic compass is influenced by the celestial pole. The magnetic poles of the earth can be demonstrated experimentally by means of a model earth fashioned from magnetite.
|            |                     |             | Two magnets can be formed by breaking a magnet. The poles of a magnet have attractive and repulsive properties. |
| c 1285-1349| Ockham, W. of       | English     | Knowledge of the material world can be gained by the method of experimental difference. |
|            |                     |             | The names of categories are not real in themselves (Nominalism), specifically finite categories like 'perfection' and 'order' cannot equate with Divine Freedom. Knowledge is gained by observation of phenomena. |
|            |                     |             | The hypothesis to choose is the simplest one that fits the facts.    |
| 1423-1461  | Peurbach, G.        | Austrian    | Ptolemy's theory does not account for the variations in the apparent diameter of the moon. |
|            |                     |             | Ptolemy's theory inadequately describes planetary motion. It is possible to transpose Ptolemy's system such that the planetary eccentric orbs centre around the sun, which travels on its sphere around the Earth. |
| 1436-1476  | Regiomontanus, J.   | German      | The human body is a suitable subject for anatomy.                    |
|            | da Vinci, L.        | Italian     | The heart works by valves.                                           |
|            |                     |             | Machines can be geometrically analysed.                              |
| 1462-1525  | Pomponazzi          | Italian     | Nature can be controlled or revealed by the use of natural magic, where a wise and religious 'Magus' is inspired to be receptive to the occult correspondences of Nature. |
| 1473-1543  | Copernicus, N.      | Polish      | The Egyptian calendar of 1 year=365 days is useful in making astronomical calculations. |
|            |                     |             | The observed motions of the stars and planets results from their movement on spheres which are mathematical models and probably real. |
|            |                     |             | The Universe appears stable, regular and subject to mathematical law, not in steady decay as widely interpreted from the Bible. |
|            |                     |             | The Earth is curved.                                                 |
|            |                     |             | Each type of matter, whether on earth, the moon or another planet, has its own 'gravity' that attracts it to the centre of its planet. |
|            |                     |             | The Aristotelian concept of levity no longer applies. The heliocentric model of the solar system is true, ie., the universe so described is real, unlike Ptolemaic astronomy, which was a useful calculational model but did not make truth claims. |
Appendix B.6: Knowledge

The temporal existence of parts of the universe is imperfect, from which they can be transmuted by alchemy. The elements can be understood through the study of alchemy. The basic power that gives life to humans, other animals, stones and spirits, is the archeus. The archeus is stimulated in therapy to oppose poisons that cause illness. Bloodletting is an outmoded practice. Chemical analysis of urine is a useful adduct to observation in medical diagnosis. Salt is the third Principle, of Solidity, besides the two identified by Aristotle, Sulfur and Mercury. The properties of substances arise from the properties of the Principles from which they are made. Disease is treated by ingestion of mineral drugs which restore the correct mix of the Principles, Mercury, Sulfur and Salt, rather than the practices of the Hippocratics and Galenists who used mainly plant derivatives. Disease results from the action of a morbid archeus in opposition to the patient’s archeus. Disease is therefore qualitatively different from health, not in a continuum as claimed by the Hippocratics. Diseases can therefore be classified and treated by specifics (remedies specific to a disease), rather than treating the symptoms in the individual patient. Diseases are also therefore distinct from the afflicted person, contrary to the notion of the Hippocratics. Mental diseases have some humoral (physiological) and some psychological bases. There are similarities between humans and the Universe, i.e., the microcosm of man reflects the macrocosm of the Universe, eg., epilepsy, which is like a thunderstorm, the curative power of yellow flowers for jaundice, and "microcosmic salt", a salt extracted from human urine. Some diseases correlate to particular occupations, which is a key to their prevention. The discovery of the New World indicates diverse human origins.

1498-1552  Osiander, A.
Copernicus' theory is useful but since we cannot demonstrate its truth cannot be claimed to be true

1514-1564  Vesalius, A.  Flemish
Human anatomy extends medical knowledge and is a means for testing existing theories. Surgery, vivisection and anatomy show that Galen's physiology is incorrect. The heart appears to comprise two distinct halves. The supposed site for the residue of vital spirit, or air or pneuma, one of the four elements, does not exist. There are animistic powers in Nature which are known by the wise, and by which Nature can be manipulated. Magnetic declination is an example of an Aristotelian occult quality. Magnetic attraction is accounted for by a sticky, elastic vapour called effluvium. Magnetite and amber attract differently.

1544-1603  Gilbert, W.  English
1535-1615  Porta, G. della  Italian

1493-1541  Paracelsus, T.  Swiss

The elements can be understood through the study of alchemy.
1546-1601 Brahe, T. Danish
Accurate and systematic observations of the sky are necessary to advance astronomy.
The accuracy of observations is improved by building larger instruments, such as sextants and quadrants, with improved sights and refined calibrations.
Celestial spheres are an inadequate description of the heavens, since the comet of 1577 travelled through where they are supposed to be.
The movement of the Earth around the sun, as proposed by Copernicus, appears to contradict Scripture, physics and astronomy.
It is more likely that the Earth is fixed, circled by the sun with the planets orbiting the sun.
Astronomical calculations can be simplified by expressing products as the sums and differences of trigonometric entities.
The bright light in the sky in 1572 is a new star, not atmospheric disturbance.

1548-1600 Bruno, G. Italian
Infinity

1561-1626 Bacon, F. British
One crucial test will indicate which of several competing theories is true.

1564-1642 Galilei, G. Italian
The pitch of sound is related to the frequency of vibration.
The 'force of vacuum' can only support a limited height of water in a pump
Copernicus' theory is a true picture of the solar system.
As suggested by Democritus, physics is concerned with the qualities inherent in bodies (size, shape, location in space and time, motion) and not in the observer, or produced by the bodies (colour, heat, sound, taste).
The physical qualities of objects can be quantified and manipulated mathematically.
The speed of light is finite, contrary to Aristotle's claim.
The speed of light is infinite.
The orbits of planets result from a balance between central and tangential forces from the Sun.
The orbits of the planets are ellipses, each with the Sun as a focus. (First Law)
As a planet orbits the sun, it sweeps equal areas in equal times. (Second Law)
The square of the time (period) for an orbit of the Sun by a planet is proportional to the cube of the mean distance from the Sun. (Third Law)
These laws are better descriptors of planetary positions than the models of Ptolemy.
The image in the eye is not received in the lens, but upside down on the retina.
Planetary motion is better explained by the notion that the resistance to move from rest is proportional to the density of a body, rather than the scholastic (Aristotelian) notion of tendency to move to its natural place.
As with Copernicus and Galileo, but contrary to Clavius and Ptolemy, the descriptions of planetary motion are true or realistic views.
Also as with Galileo and Plato, mathematics can be applied to actual or real events.
Telescope lenses can be described mathematically.

Table B.6.2 is a rough chronology of ideas in the development of science. These ideas include scientific (content) knowledge, ideas about how to 'do' science (scientific process) and ideas about science (metascience). They are presented as simple statements or propositions which summarise the principle idea involved. They do not include commentary.
on the statement, or any other background information, so that as a set they are intended to convey a progression of knowledge propositions; no comments are given about theoretical developments, which are discontinuous and sometimes concurrent. The set, therefore, includes ideas that have been falsified or discarded. Because the set has a chronological, rather than thematic, format, it is possible to see the concurrent development of different areas.

The chronology is ‘rough’ in four senses. Firstly, the dates are not given for the publication of ideas, but rather the life-dates of the person. This avoids the complications of not knowing exactly when some ideas were made public, and leaves aside discussion of how long an idea may have taken to become generally accepted. (Some ideas, are not yet universally accepted; in any case, scientific ideas are always open to revue, and there is no absolute measure of acceptance.) Such discussion is beyond the purpose of this chronology.

Secondly, there are many ideas (and their proponents) which have not found their way into this chronology, but could have been included. Related to the second point is the third point, that a few inclusions might be argued not to be as significant as some omissions. This essentially reflects editorial judgement in attempting to balance the competing goals of detail against overview, to convey a sense of history and to illustrate the development of major ideas. For example, some have been included because their names have become associated with a structure or law and are therefore known to us, whereas others who may also have contributed to that same discovery have been omitted.

Fourthly, the statements under *contribution* are couched as summary statements so that, as a set, they read as a type of cumulative summary of knowledge. They are not intended to be comprehensive, either in the sense of all the contributions of each person, or as definitive statements of the ideas included, or of external factors in the production of this knowledge.
Pollock's (1986) Categorisation of Theories of Knowledge

<table>
<thead>
<tr>
<th>Category</th>
<th>DOXASTIC theories hold that our beliefs are justified exclusively in terms of the beliefs we already hold - our doxastic state.</th>
<th>NON-DOXASTIC theories hold that our beliefs are partly justified in terms of the beliefs we already hold but also in terms of other nondoxastic considerations.</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTERNALIST theories hold that beliefs are justified in terms of the internal states of the believer.</td>
<td>Beliefs can only be justified by appeal either to basic, self-justifying beliefs, such as simple beliefs about sense perceptions, (foundations theories), or to the general coherence of epistemologically equal beliefs (coherence theories).</td>
<td>Direct realism, for example, holds that beliefs are justified at least partly in terms of perceptual states themselves, and not just in terms of beliefs about the perceptual states.</td>
</tr>
<tr>
<td>EXTERNALIST theories hold that beliefs are justified in terms of more than the internal states of the believer.</td>
<td>None; logically excluded</td>
<td>There are various theories fitting this category. For example, according to reliabilism beliefs are justified to the extent they are produced by reliable cognitive processes, while according to probabilism they are justified to the extent of their probably being true.</td>
</tr>
</tbody>
</table>
### Table B.6.4
Developments in science knowledge reported in June 1996 in two journals, as given in headlines/story by-lines

<table>
<thead>
<tr>
<th>Issue</th>
<th>Stories on front cover</th>
<th>Stories in science update section</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 June 1996</td>
<td>Reinventing the city</td>
<td>Tumour origins</td>
</tr>
<tr>
<td></td>
<td>Squatters take control</td>
<td>Friendly toxin</td>
</tr>
<tr>
<td>Vol. 150</td>
<td>Symbiotic factories</td>
<td>Tadpole galaxies (Discrepancy between cosmological theory and test results)</td>
</tr>
<tr>
<td>No. 2032</td>
<td>Playing with chaos</td>
<td>Treadmill illusion</td>
</tr>
<tr>
<td></td>
<td>Useful noise</td>
<td>Freshwater whales (Whale evolution)</td>
</tr>
<tr>
<td>8 June 1996</td>
<td>Why you could catch a heart attack</td>
<td>Sleeping echidnas</td>
</tr>
<tr>
<td>Vol. 150</td>
<td>Tiny black holes</td>
<td>Quantum cation</td>
</tr>
<tr>
<td>No. 2033</td>
<td>Fire engines in the sky</td>
<td>Weird matter (New state of matter pictured at last)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Breast cancer setback (Not guilty verdict on cancer gene)</td>
</tr>
<tr>
<td>15 June 1996</td>
<td>Alien Earth - the seven new worlds</td>
<td>Male infertility</td>
</tr>
<tr>
<td>Vol. 150</td>
<td>Real-time evolution</td>
<td>Sociable shrimps</td>
</tr>
<tr>
<td>No. 2034</td>
<td>Rongorongo wrangle</td>
<td>Cosmic fireballs (Strange matter of the early Universe)</td>
</tr>
<tr>
<td></td>
<td>Automated Singapore</td>
<td>Sailing goes quantum (Explanation of sailing lore by quantum physics)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Plant power (Renewable energy)</td>
</tr>
<tr>
<td>22 June 1996</td>
<td>Life at two hundred - will we always grow old?</td>
<td>‘Junk’ DNA (New interpretation of repeated DNA sequences)</td>
</tr>
<tr>
<td>Vol. 150</td>
<td>Seeing through the sea</td>
<td>Comets’ origins</td>
</tr>
<tr>
<td>No. 2035</td>
<td>Who owns the dead?</td>
<td>Secret of the young Sun (Comet clues to missing neutrinos)</td>
</tr>
<tr>
<td></td>
<td>Diary of a mathematician</td>
<td>Secret of the young Sun</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Secret of the young Sun and the Dead Sea</td>
</tr>
<tr>
<td>29 June 1996</td>
<td>Machines that dance on a pinhead</td>
<td>Enzyme pushes cell’s self-destruct button</td>
</tr>
<tr>
<td>Vol. 150</td>
<td>High and dry in Columbia</td>
<td>Embryos under stress (Why stressful lives begin before birth)</td>
</tr>
<tr>
<td>No. 2036</td>
<td>Deep-sea salvage</td>
<td>Enzyme pushes cell’s self-destruct button</td>
</tr>
<tr>
<td></td>
<td>Down with state funding (for science)</td>
<td>Enzyme pushes cell’s self-destruct button</td>
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<tr>
<td></td>
<td></td>
<td>Enzyme pushes cell’s self-destruct button</td>
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<tr>
<td></td>
<td></td>
<td>Enzyme pushes cell’s self-destruct button</td>
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<tr>
<td>Issue</td>
<td>Story on front cover</td>
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<td>-------------</td>
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<tr>
<td>6 June 1996</td>
<td>The Universe observed</td>
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<td></td>
<td>Pyroclastic flows reconsidered</td>
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<td></td>
<td>Directing mRNA splicing</td>
<td></td>
</tr>
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<td></td>
<td>A sociable shrimp</td>
<td></td>
</tr>
<tr>
<td>13 June 1996</td>
<td>Neurons get their timing right</td>
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<tr>
<td></td>
<td>TGF-β signalling goes <em>Mad</em></td>
<td></td>
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<tr>
<td></td>
<td>The anelastic Earth</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A galaxy too old</td>
<td></td>
</tr>
<tr>
<td>20 June 1996</td>
<td>Giant lake beneath Antarctic ice</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Neurobiology of sign language</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stiffness of nanotunes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>HIV co-receptor</td>
<td></td>
</tr>
<tr>
<td>27 June 1996</td>
<td>A matter of taste</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Genetics of male infertility</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aurorae shun the light</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Financial turbulence</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX C

Summary statements of technology
APPENDIX C

Summary statements of technology

A collection of summary statements of technology from the literature

T.1 '[Technology is]
1. the branch of knowledge that deals with science and engineering, or its practice, as applied to industry; applied science;
2. the terminology of an art, science, etc.; technical nomenclature.'
*The Macquarie Dictionary* 1985

T.2 '(Technology is) the results of man's [sic] equally natural desire to find ever new and better ways of satisfying his needs, of achieving his goals, of doing the job he wants done.'
Foecke 1984, p.2

T.3 'The purpose behind a technological activity is to facilitate human aspiration: to solve some practical problems; to put knowledge to good use; to extend the boundaries of existing possibilities.'
Foecke 1984, p.2

T.4 'Technology is the application of science and other forms of organised knowledge towards a specific practical outcome.'
Lowe 1987b, p.117

T.5 'Technology is a perishable resource comprising knowledge, skills and the means of using and controlling factors of production for the purpose of producing, delivering to users, and maintaining goods and services for which there is an economic and/or social demand.'
*Definition from the U.S. National Academy of Science, adopted by the Commonwealth Department of Science and Technology and accepted by the Senior Secondary Assessment Board of South Australian for their Year 12 Technology Studies Syllabus, c1989*

T.6 'Technology is a process whereby techniques of researching, designing and making are applied to and through human, material and energy resources to make and control end products which will satisfy needs.'
Gilbert 1988, p.5

T.7 'Technology is a disciplined process using resources of materials, energy and natural phenomena to achieve human purposes.'
*Black & Harrison 1985*

T.8 'Technology is the application of scientific, material and human resources to the solution of human needs.'
*Williams & Jinks 1985, p. 50*

T.9 'Technology is the construction of useful objects and materials, and the organisation of human activity to meet ends.'
*McKenzie 1987, p. 170*

T.10 '(Technology is) the study of the application of science and scientific knowledge, especially to industry.'
*Heinemann Australian Dictionary, 2nd Ed.*

T.11 'Technology is defined as the systematic process of designing, improving, producing and maintaining artefacts - and the artefacts themselves.'
*Genoni, c1984, quoted in NSW Department of Education 1988*

T.12 'While the term "science" can claim some degree of clarity and precision, no such claim can be made for "technology". The term is used to designate a wide variety of tools, systems, products,
complexes of activities and so on. Lewis Mumford and other historians and philosophers of technology have attempted to introduce a more precise and discriminating vocabulary to distinguish among a wide variety of quite distinct phenomena, but the term is still popularly used in a way which confuses rather than clarifies issues.

The most commonly accepted precise definition of technology is the deployment of matter, energy and information for human purposes. In this definition, technology is considerably more than, and qualitatively different from, "applied science", even though it is science-based, and is at least potentially, fundamentally different from "technocracy". Technocracy is what Jacques Ellul has described as the triumph of the kingdom of means. It is the design and deployment of technical systems and skills divorced from a serious consideration of human purposes.

Technology, in its popular sense, can also be considered and analysed as process, product, institution, myth and ideology. Its technocratic manifestation, especially, has the character of ideology in that technical skills and systems, often claimed to be value-neutral, are, nevertheless, designed, developed, and deployed within a well-defined structure of economic and political relationships and a deeply established set of social priorities. The design imperatives are so totally taken for granted that the values inherent in them and socio-economic biases they embody are not even recognised as such.'

Kenny 1988, p 24

T.13 'Technology is often thought of as the practical developments and applications of Science. It might more suitably be considered as the purposeful use of human knowledge of materials, sources of energy and natural phenomena. In many cases technological applications have been developed from scientific knowledge, but also many scientific advances have followed on after the Technology. The development of metals for various uses, for example, and the knowledge of the chemistry of metals grew up together. Recently the word Technology has taken on new meanings with the development and use of computers and other new technologies associated with such areas as genetic engineering and electronic devices.

The ideas and methods of Science and those of Technology clearly have a great deal in common. And it is over simplistic to think of Science as theoretical and Technology as practical; both have theoretical and practical aspects. For these reasons it is appropriate to think of Science and Technology as one area ... It is the attitudes, skills and methods of Science and Technology which set it apart from other areas rather than the particular content studied.

A.C.T. Schools Authority 1984, p.2

T.14 'Technology ... is a perishable resource comprising knowledge, skills and the means of using and controlling factors of production. The application of this knowledge results in the production, delivery and maintenance of goods and services for which there is an economic and/or social demand.'

Education Commission of N.S.W. c1987, p. 2

T.15 'As long as there have been people, there has been technology. Indeed, the techniques of shaping tools are taken as the chief evidence of the beginning of human culture. On the whole, technology has been a powerful force in the development of civilisation, all the more so as its link with science has been forged. Technology - like language, ritual, values, commerce and the arts - is an intrinsic part of a cultural system and it both shapes and reflects the system's values. In today's world, technology is a complex social enterprise that includes not only research, design, and crafts, but also finance, manufacturing, management, labour, marketing, and maintenance.

In its broadest sense, technology extends our abilities to change the world: to cut, shape, or put together materials; to move things from one place to another; to reach further with our hands, voices, and senses. We use technology to try to change the world to suit us better. The changes may relate to survival needs such as food, shelter, or defence, or they may relate to human aspirations such as knowledge, art, or control. But the results of changing the world are often complicated and unpredictable. They can include unexpected benefits, unexpected costs, and unexpected risks - any of which may fall on different social groups at different times. Anticipating the effects of technology is therefore as important as advancing its capabilities.'

Project 2061, AAAS 1993, p.41

T.16 'Technology is an overworked term. It once meant knowing how to do things - the practical arts or the study of the practical arts. But it has also come to mean innovations such as pencils, television, aspirin, microscopes, etc., that people use for specific purposes, and it refers to human activities such as agriculture or manufacturing and even to processes such as animal breeding or voting or war that change certain aspects of the world. Further, technology sometimes refers to the industrial and military institutions dedicated to producing and using inventions and know-how. In
any of these senses, technology has economic, social, ethical, and aesthetic ramifications that depend on where it is used and on people's attitudes toward its use.'

*Project 2061, AAAS 1993, p.43*

T.17 'Technology is even older than mathematics and science. Indeed, the latter may both have developed at first in response to the need to build things and solve practical problems, although discoveries in science and mathematics today often precede practical uses. In any case, although technology still has a life of its own, it is becoming much more closely tied to mathematics and science and hence is an essential part of the scientific enterprise. Understanding technology and its connections to science and mathematics is therefore necessary for science literacy.'

*Project 2061, AAAS 1993, p.323*

T.18 'Following a concert given by Fritz Kreisler, a woman came up to him and said, "Maestro, your violin makes such beautiful music." Kreisler held his violin up to his ear and responded, "I don't hear any music coming out of it." Melvin Kranzberg, in presenting this story, then observes, "when men [sic] and machine work together, they can make some beautiful music." In this context, Kranzberg is viewing machines, tools, technical artefacts and technique as one, a conflation that I will show later is misleading. Each of these manifestations is however a member of the general species, "technology".

The story and Kranzberg's observation directly align with the original Greek conception of what technique and knowledge were, the two Greek epistemic roots from which the modern-day meaning of "technology" was derived. The ancient Greeks had a world view that asserted human engagement with the natural world. This world view is quite different to the contemporary world view of industrialised society which places science on a pedestal as an independent arbiter of what is valid in human experience and constructions of meaning. Science, for the Greek philosopher Pythagoras, involved "the study of the comely and harmonious order of the world." Greek science was more to do with the human engagement in the aesthetic of the "Kosmos" (or "comely order" of things), as in Pythagorean geometry, than it was to do with the separation fostered within post-Baconian science between an eternal reality and its human observation. Similarly, the Greek root for "technology", techne, is to do with not only the activities and skills of the craftsman, but also comprises the arts of the mind, and the fine arts. Techne, like science, involves an aesthetic, or as Heidegger describes it, a "bringing forth to poiesis", or the human construction of poetic meaning within technique. For the ancient Greeks,

Beauty lay in the potential for meaning which realised the object, an object simultaneously useful, integrated and integral, or rather, both the product and production of nature prescribed by a unifying vision of the world, gathering about it and in it the milieu from which it took root.

The "ology" part of the word "techne-ology" refers to knowledge about techne, literally, "words of knowledge". Thus, the cultural roots from which the word "technology" has been derived are deeply planted in human engagement in a world that the people are crafting, transforming and gaining knowledge about, as a harmonious and poetic synthesis constituted within the relationship between humans and nature. This perfectly expressed the relationship between Fritz Kreisler and his violin.

However, by the time "technology" came to be defined by the American Webster's dictionary, its meaning had fundamentally shifted to "the application of science to industrial use". Within this definition, "technology" still concerns a mode of revealing to human consciousness, as Heidegger would claim. However, what is 'revealed' is only that which can appear through the filter of rationality and the application of rationality within industrialism. As opposed to the holistic view of the ancient Greeks, contemporary "technology" is seen more as associated with a means to an end than it is with human activity and construction of meanings. Within the modern experience of technology, the person is a component in a collective enterprise that connects technical means with productive ends. Thus, the end that Kreisler could accomplish as a virtuoso violinist may express human harmony. But the experience that people have of technology generally is very different indeed.'

*Hill 1988, pp. 37-8 (emphases in original)*

T.19 'Consequently, whilst the definition of "technology" has been derived from ancient Greek cultural roots, the aesthetic order that houses human experience, and the meaning of "technology", is now fundamentally different. As far as the Greeks were concerned, the aesthetic was one of harmony derived from human engagement. As far as modern society is concerned, the aesthetic is one of harmony between smoothly integrated technical systems, a harmony that mirrors the assertion of "instrumental" over "communicative" action. The modern technological aesthetic has as its fundamental dimension externally-mediated power and control over both the use of nature and humanity's definition of it. Thus, whilst "men and machines working together can make some
beautiful music" in any culture, for the Greeks the harmony is the music of human engagement, and for the modern world, the harmony is the music of smoothly meshed, quietly humming technical systems.

Hill 1988, p.39

T.20  ‘[W]hat determines the level of opacity or transparency of the artefact text is the level of alignment between the stock of knowledge that we have access to within our life-world experience, and the stock of knowledge that is hidden within the artefact. Thus, returning to the original definition of the word, “technology”, the “species” is defined in terms of knowledge rather than mere physical object, but within the species, the distinction between the separate identities of tool and machine - as far as life-world experience and mediation of relationships is concerned - is a distinction between the level of knowledge embodied, and the accessibility of this knowledge to life-world experience and construction.’

Hill 1988, p.43 (emphasis in original)

T.21 ‘Technology is the practical method which has enabled us to raise ourselves above the animals and to create not only our habitats, our food supply, our comfort and our means of health, travel and communication, but also our arts - painting, sculpture, music and literature. These are the results of human capability for action ...

Technology is a disciplined process using resources of materials, energy and natural phenomena to achieve human purposes.’

Black & Harrison 1985, p. 3
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