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Sharon Beder
University of Wollongong, sharonb@uow.edu.au

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BEYOND TECHNICALITIES: EXPANDING ENGINEERING THINKING[a]

By Sharon Beder[1]

ABSTRACT: Engineering appears to be at a turning point. It is evolving from an occupation that provides employers and clients with competent technical advice to a profession that serves the community in a socially responsible manner. Traditional engineering education caters to the former ideal, whereas increasingly both engineers themselves and their professional societies aspire to the latter. Employers are also requiring more from their engineering employees than technical proficiency. A new educational approach is needed to meet these changing requirements. It is no longer sufficient, nor even practical, to attempt to cram students full of technical knowledge in the hope that it will enable them to do whatever engineering task is required of them throughout their careers. A broader, more general approach is required that not only helps students to understand basic engineering principles but also gives them the ability to acquire more specialized knowledge as the need arises.

FUTURE WORK SKILLS

If engineers are to be more than technical functionaries in the next millennium, there is a need to provide young engineers with an understanding of the social context within which they will work, together with skills in critical analysis and ethical judgement and an ability to assess the long-term consequences of their work. Engineering in the modern world also involves many social skills. These include the ability to understand and realize community goals; to persuade relevant authorities of the benefits of investing money in engineering projects; to mobilize, organize, and coordinate human, financial, and physical resources; to communicate and motivate; and to advise on many social, environmental, and safety aspects of their work (Webster 1996).

To be a good engineer today, ‘‘technical virtuosity is often necessary, but never sufficient’’ (Webster 1996). The colloquial definition of engineering—‘‘the art of doing that well with one dollar, which any bungler can do with two after a fashion’’—is no longer adequate to describe the vast diversity of skills required by the modern engineer.

There is also an increasing need for engineers to choose technological solutions that are appropriate to their social context and to give consideration to the long-term impacts of their work, if only because the work of engineers can have wide-ranging effects. Today's technologies can affect the whole globe and future generations. Never before has there been such a moral imperative to consider what may have been thought of as unintended consequences in the past.

The U.S. Board on Engineering Education published a report on engineering education (*Engineering* 1995) which stated:

> There is a widening recognition of the responsibility of engineers to consider the social and environmental impact of their work. In sharp contrast to the attitudes and practices that prevailed at mid-century and before, engineers today are required to design sustainable systems that consider as crucial inputs the environmental impact of their manufacture and use, their accessibility to people of diverse ethnicity and physical abilities, their safety, and their recyclability. (p. 14)

Yet appropriate technologies that minimize environmental and social consequences are often not widely adopted for social and political reasons, and engineers need to be aware of this. Langdon Winner (1986) has argued that most people in the appropriate technology movement ignored the question of how they would get those who were committed to traditional technologies to accept the appropriate new technologies. They believed that if their technologies were seen to be better not only in terms of their environmental benefits but also in terms of sound engineering, thrift, and profitability, they would be accepted.

Many of the advocates of appropriate technologies made no attempt to understand how modern technologies had been developed, why they had been accepted, or why alternatives had been discarded. Winner claims that ‘‘by and large, most of those active in the field were willing to proceed as if history and existing institutional technical realities simply did not matter’’ (1986, p. 80). Similarly, today, clean technologies will not be implemented without social factors being addressed. Having the technological means to reduce pollution and to protect the environment does not mean that it will automatically be used (Beder 1996). Those who design new and more benign technologies also need political and social understanding to ensure they do not remain merely interesting inventions that are not adopted.

Employers are also recognizing the deficiencies in traditional educational curricula in providing graduates with social skills. An Institution of Engineers, Australia (IEAust), survey of Australia's major engineering employers identified several areas in which engineering graduates would be required in the future, but ‘‘more than 97 percent of respondents concluded that their current engineers did not have the necessary skills or experience to carry out their duties to ‘an acceptable level of competence’ ’’ (Bitcon 1993). Lacking were the social understanding, human interaction, and written communication skills not traditionally part of an engineering degree. A recent Australian review of engineering education noted:

> In the business world, engineers are often seen as being preoccupied with technical issues to the exclusion of all else, unwilling or unable to appreciate contextual imperatives or to contribute effectively to business and political decisions. This has probably been the main factor leading to the ‘de-engineering’ of the public sector, and to the view of engineering as a commodity to be purchased when needed—not a critical strategic capability requiring long-term investment and development, or an integral part of decision-making. (*Changing* 1996, p. 54)

Similarly, the lack of ‘‘breadth of vision and the ability to communicate effectively, or take the lead’’ has lost engineers top positions in government organizations in Australia (*Chang-*

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[1]Assoc. Prof., Sci. and Technol. Studies, Univ. of Wollongong, NSW 2522, Australia. E-mail: sharon_beder@uow.edu.au

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ing 1996, p. 55). The proportion of engineers who head public work agencies is also declining in the United States. The numbers of heads of public works agencies surveyed who had civil engineering degrees dropped from 69% in 1955 to 32% in 1989 (Carlile 1990).

A new avenue for employment of engineering students from elite U.S. engineering schools has been financial firms, with 14% of engineering graduates at MIT being recruited into such firms in 1995. These engineers are being hired not for their traditional engineering know-how but rather for their problem-solving skills, which their employers believe will be useful in the world of business and finance. In addition, their computer and mathematical skills come in handy as financial transactions become more complex (Solomon 1996). However, engineers hired into the world of finance remain subservient to people with MBAs and are overlooked for management positions because of their lack of leadership skills:

> Many engineers fall short on the strong interpersonal skills needed to forge consensus in a large organization and to deal effectively with customers and vendors. Without extensive exposure to the humanities, many engineers also lack broad cultural references as well as good verbal and writing abilities (Solomon 1996)

PUBLIC IMAGE OF ENGINEERS

Due to the past emphasis on technical skills and the consequent neglect by engineers of social and environmental dimensions of their work, the image and status of the engineering profession is declining, as the public identifies engineers with controversial and environmentally damaging technologies. Engineers are too often characterized as being male, socially inept, politically naive, and aligned with self-serving developers; and they are finding themselves at the center of controversies they don't fully understand. Increasingly, engineers are subjected to lawsuits because the public, which has an unrealistic perception of the nature of engineering, blames them when things go wrong.

Cartoonists in English-speaking countries tend to portray the engineer as ''a nerdy-looking character, with thick glasses, short hair, several pens and pencils in his shirt pocket, perhaps in a plastic pocket protector, wearing clothes that are never quite up to fashion'' (Braham 1992). The ''nerd'' stereotype of the engineer arises in part from the emphasis on technical aspects of the profession.

In Britain, engineering is ''seen as dirty, boring, unfulfilling, and financially unrewarding,'' says Robert Payne, an engineer at the Polytechnic of Wales. British engineer K. Strauss (1988) has suggested that the engineer is ''seen as a soulless apparatchik, building ever taller, slicker, quicker, more coldly efficient devices that few want and that fewer can afford, which from time to time go hideously wrong'' (p. 262). Over the past two decades, various official inquiries have been made into the decline in status of the British engineer since the glory days of the early 19th century, when engineers were the heroes of poetry and novels.

The U.K. magazine *Professional Engineering* published an article entitled ''Is there a bit of the Rain Man in every engineer?'' linking engineers with children who have autism. Autistic children do not develop normal social relationships, and they tend to wander off by themselves and play with mechanical things. The article said that engineers and autistic children share various characteristics including strong visualization skills, strong affinity with physical objects, and being ''less interested in social activities and communication.'' It cited a study by Simon Baron-Cohen, an autism specialist, which found that ''the parents and grandparents of autistic children are twice as likely to be engineers as the national average for all occupations would suggest.'' In a sample of 820 autistic children's families, there were 100 fathers who were engineers and 80 grandfathers (Dunn 1996).

A U.S. survey of public attitudes towards engineering found that the public thought of engineers as having ''poor social skills'' and being ''self-absorbed, loners, rigid with a one-track mind'' (Braham 1992). Yet this is not so far from the way some engineers see themselves. System engineer Doug Brown describes engineers as goal-oriented, reluctant to be distracted by extraneous information even if it is related to what they are doing, ''passive and docile; poor managers of people, who possess weak interpersonal skills and who don't handle personnel conflicts well; conservative; curious tinkerers, and men who are not gregarious but who do congregate together and enjoy their own company'' (Braham 1992).

Engineer/cartoonist Scott Adams describes an engineer who goes off to work with a sock ''static clinging'' to the back of his shirt and comes home at the end of the day with it still there and without anyone having mentioned it to him at work. Adams says that this would only happen to an engineer in an engineering environment, where everyone is focused on and absorbed in their work: ''the single most identifying aspect of the engineer's personality is the ability to go a mile deep in some specific subject, but be blind to things on either side. He has an incredible ability to become very intense in certain subjects, often at the expense of social awareness or some broader interests'' (Braham 1992).

Norman Augustine, in an award acceptance speech at the National Academy of Engineering in the United States, referred to engineering as ''the stealth profession, the silent occupation'' because engineers' unwillingness to speak publicly about engineering issues. He pointed out that only eight out of 535 members of Congress listed their occupations as engineers and argued that engineers were abdicating ''our obligation to serve in positions of responsibility in the area of public policy formulation'' (Braham 1992). Yet the government bureaucracy is not short of engineers, with significant numbers in top positions, where they work away from the public spotlight, accorded to elected officials (Petroski 1986).

Petroski notes the preponderance of lawyers in political office and suggests that a traditional engineering education does not prepare engineers for such positions:

> The rhetorical skills prerequisite to a successful political career are as dulled in engineering schools as they are honed in law skills. . . . The modern technical lecture, perhaps the paragon of technical communication today, often takes place in a darkened auditorium with the speaker's back to the audience composed of his [sic] technical peers. (p. 89)

SELECTION AND RECRUITMENT OF ENGINEERS

Whatever the reasons, the poor image of engineering has consequences that go beyond the egos of engineers. If school students have a poor or nonexistent image of engineering, they are hardly likely to choose it as a career, and this could potentially lead to a shortage of engineers and even a decline in engineering standards. In Australia, the examination scores necessary to get into engineering schools have been falling for traditional engineering degrees, although they are high for combined engineering and arts degrees and also for environmental engineering degrees.

High-school students usually have very little grasp of what engineers really do. IEAust surveys have found that school students tend to think of engineering as a job concerned with objects and gadgets rather than people. Also, the community does not have a solid picture of what engineers do beyond their involvement in construction of machines and buildings.

Students are forced to make their choice on criteria other than the sort of work they can expect to do as engineers. Recruiters in the United States, who are looking to increase the numbers of females and minority groups doing engineering because of the decline in numbers of engineering students, have found that ''the main reason engineering programs do not attract women is the profession's negative image'' (Baum 1990).

The image of engineering traditionally conveyed by engineering schools through their selection criteria and course content is of a field of endeavor that is overwhelmingly concerned with numbers, science, and mathematical analysis. This has been an important influence on students' choice of engineering as a career.

The consequently narrow range of people traditionally attracted to and allowed into engineering has resulted in the development of a stereotype of the engineer common to several English-speaking nations, as discussed earlier. Elements of this stereotype have their roots in the characteristics of engineers graduating in earlier decades. Surveys from the 60s and 70s found that engineers had a fairly narrow range of interests; disliked ambiguity, uncertainty, and controversy; and preferred things to be ordered and precise. They were unlikely to question authority. In particular they were not ''people oriented,'' nor were they interested in the humanities or the social sciences (Davenport and Rosenthal 1967; Perucci and Gerstl 1969; Kirkman 1973; Hutton and Lawrence 1981). Engineers at the time rated themselves as strong in technical ability, desire to excel, and persistence, but weak in ability to communicate, social amenities, and culture (Davenport and Rosenthal 1967).

While such generalizations are usually of limited use, they were more true for engineers than for other professionals because of the narrow base from which engineers were drawn. A research group that analyzed a number of studies of engineers noted:

> It is therefore probable that unlike many other occupations where it is impossible to demonstrate any consistent trend as far as personality traits are concerned, the engineering profession—with the exception of research, administrative and sales specialties—is composed of a homogeneous group of men with a fairly narrow range of temperamental variation. (Florman 1976, p. 92)

Samuel Florman, in his book *The existential pleasures of engineering* (1976), which extolled the engineering heroes of the past, blamed the fall of the engineer into an insipid reflection of its former glory partly on ''the stultifying influence of engineering schools where the least bit of imagination, social concern, or cultural interest is snuffed out under a crushing load of purely technical subjects'' (p. 92). But primarily, he saw the problem as the type of young person who chooses to become an engineer. The ''typical engineering student is the serious, intelligent, unexciting young person'' who tends to be indifferent to human relations, social sciences, public affairs, social amelioration, and cultural subjects (pp. 91–92).

The two problems Florman identifies—the effect of engineering education and the type of person choosing engineering—are not unrelated. The load of technical subjects that constituted the greater part of so many engineering courses gave prospective students an image of engineering that did not adequately represent the profession. This distorted picture of an engineering career, disembodied from any social context, was therefore only attractive to a narrow range of young people who were willing to forsake professional involvement with people, public affairs, and a wider set of social concerns.

The narrowness of engineers may have been of concern to those within the profession, such as Florman, who had some nostalgic vision of a time when engineers were cultured gentlemen of influence. Of far more importance, though, are the consequences to a society of having its technology developed and shaped by people who lack imagination and creativity and who prefer not to know much about the wider world of people and consequences.

HISTORICAL REASONS FOR TECHNICAL FOCUS

Engineers have long been unhappy with their status in society. They feel that they do not receive the social respect and financial rewards that people in other professions, e.g., law and medicine, do. Practicing engineers and professional engineering societies have traditionally seen an emphasis on science as a means of gaining status. Engineers came to define themselves by their ability to apply scientific laws to achieve their ends:

> The cement binding the engineer to his profession was scientific knowledge. All the themes leading towards a closer identification of the engineer with his [or her] profession rested on the assumption that the engineer was an applied scientist. (Layton 1971, p. 58)

A specialized knowledge base was also sought keenly by engineers as a basis for their claim for professional status. In particular, civil and mechanical engineers required science as part of their specialized knowledge base so that they would be differentiated from the technicians, mechanics, and skilled craftsmen in the occupational hierarchy.

Science and mathematics training is, of course, essential to an engineering career these days. The old trial-and-error design methods of the eighteenth and nineteenth century were gradually replaced by scientific and calculation based methods that were necessary for the more complex nature of modern technology. However, the heavy emphasis on mathematics and science in engineering courses was spurred and reinforced by the need for status amongst engineering educators.

> It is usually a shock to [engineering] students to discover what a small percentage of decisions made by a designer are made on the basis of the kind of calculation he [or she] has spent so much time learning in school. (Ferguson 1992, p. 1)

University education, in the past, had as much to do with providing credentials and prestige to a fortunate group of young people as it has with equipping students with vocationally relevant skills. In fact, education that was vocationally oriented was looked down upon in both Britain and the United States during the nineteenth century. Common people were trained for a specific vocation, whereas ''gentlemen'' were educated (Ahlstrom 1982). Attempts to set up engineering schools offering practical training as opposed to ''education'' were unsuccessful. If young people wanted practical training, they could get it on the job; they went to school for the prestige of an education, and vocational schools did not offer this.

However, as science gained status, engineers sought to share that status. Scientific education came to have a certain amount of prestige because of ''a small but prominent and growing profession, that of the scientific researcher'' (Collins 1979, p. 124), and this prestige had its effect on engineering education. The educators in early engineering schools, operating within universities, were highly conscious of their second-class status, and even the newly esteemed scientists looked down upon them. One way of improving status was to increase the scientific content of their courses and thereby to ''capitalize on the growing respectability of science'' (Noble 1977, p. 26).

PROBLEMS WITH OVERLY SCIENTIFIC APPROACH

The scientific approach has, of course, yielded solutions to engineering problems which the old trial-and-error methods never could, but the need to teach science in engineering schools has been grossly inflated by the needs of the engineering profession for esoteric knowledge and those of engineering educators for academic respectability (Noble 1977). These needs, superimposed over the basic vocational needs of the future engineer, have meant that the curriculum has become grossly overcrowded and dominated by science, to the detriment of other subjects. Douglas Clyde (1995), a former president of the IEAust, observes:

> For many years, twentieth century engineering education has required as the foundation for all engineering disciplines a knowledge base in classical mathematics, physics, and chemistry that is in many ways identical to that required by a physical scientist. Unfortunately, this has led to the perception which is very difficult to dispel that engineering is simply a subset of physical science, and this has to some extent shaped engineering education because of its influence on decisions on resource allocation and career structure.

Another problem is that a tightly packed syllabus, full of science and maths and specialized technical subjects, left little room for expansion into broader areas of concern. Most Australian engineering degree courses have traditionally been filled with the technical, the mathematical, and the scientific to the almost complete neglect of the social, political, and environmental issues (not to mention the managerial and industrial relations aspects) that shape engineering practice in the real world. Where such issues have crept into the courses, they are usually treated as secondary and even unimportant considerations. This is something the recent review of engineering education seeks to change:

> The present emphasis placed on engineering science, resulting in graduates with high technical capability, has often acted to limit their appreciation of the broader role of engineering professionals. Graduates must understand the social, economic, and environmental consequences of their professional activities if the profession is fully to assume its expanding responsibilities. (*Changing* 1996, p. 7)

Various qualities have been identified as important to engineering that are not engendered by a wholly technical curriculum, such as judgement, experience with and understanding of social complexities, creativity, and visual skills. Inevitably, this affects the end products of engineering work. Eugene Ferguson (1977) noted that the nonscientific component of technology has been neglected in engineering education because its origins lie in art rather than science. He argued that, in modern times, verbal and mathematical thought have come to be considered superior because perceptive processes are not supposed to involve ‘‘hard thinking’’ and because nonverbal thought is seen as more primitive. As a result, engineering courses have favored and taught analytical skills. This neglect has its consequences: ‘‘In the longer run, engineers in charge of projects will lose their flexibility of approach to solving problems as they adhere to the doctrine that every problem must be treated as an exercise in numerical systems analysis’’ (p. 834).

In scientific courses, students learn that there is only one right answer to the problems they are set. If the question is ambiguous, then the lecturer is at fault in setting such a question. Yet there is seldom only one solution to real-life problems, nor is there one way of going about things. An MIT report on engineering education found that this did not encourage the development of engineering judgement: ‘‘Skepticism and the questioning attitude are not encouraged in this situation. . . . Neither the data, the applicability of the method, nor the result are open to question’’ (Ferguson 1977, p. 163). According to Ferguson:

> The real ‘problem’ of engineering education is the implicit acceptance of the notion that high-status analytical courses are superior to those that encourage the student to develop an intuitive ‘feel’ for the incalculable complexity of engineering practice in the real world. (p. 168)

The overemphasis on science in engineering has led not only to a neglect of social dimensions by engineers but also a faith in technological solutions that is often not warranted. A recent Australian Taskforce on Students and Engineering observed:

> Engineering has long been restrained by its technological approach to problem solving. Its perceived choice between possible technical approaches to a problem have not only narrowed its vision but, increasingly of late, responsibility for these decisions has been handed over by engineers to others, notably their ‘corporate or political masters.’ (‘‘Interface’’ 1996a, p. 39)

Education is an important factor in the narrowing of engineering outlooks. A study which compared students in and graduates from conventional engineering courses in Britain with those in ‘‘enhanced’’ management-oriented engineering courses found that, while students who were more interested in management tended to choose or be selected for the ‘‘enhanced’’ engineering courses, these students had a declining technical orientation as they progressed through the courses compared with the students doing conventional engineering courses, indicating that engineering education is influential in forming graduate attitudes and career orientations (Keenan 1994).

TECHNOLOGY AS SOCIAL ACTIVITY

Engineering work is clearly a social and political activity, although this has been ignored in engineering education. There is never just one possible design; ‘‘engineering design is surprisingly open-ended. A goal may be reached by many, many different paths, some of which are better than others, but none of which is in all respects the best way’’ (Ferguson 1992, p. 23). An engineering design is more than a product of analysis. It is inevitably influenced by past technologies, the personal preference of the designer, intuition about what is appropriate and will fit the requirements, and cultural and social factors. Design is a social process, involving interaction between the design team, the client, and others (Ferguson 1992).

Peter Weingart (1984) wrote of ‘‘orientation complexes,’’ which orient technological development in a particular direction. The most important nontechnical orientation complex is economic. Economic criteria have not only a ‘‘selective function’’ of influencing the choice between different technical possibilities, but are also built into the technologies via concepts such as durability, speed, and efficiency. Economic orientation complexes are institutionalized in the market but also in corporations that are organized around a particular technology.

A second set of orientation complexes, wrote Weingart, comes from the political system. These can be ‘‘selective’’ or ‘‘determining’’ as well and are institutionalized in laws and regulations. A third set of orientation complexes are cultural but these seem less and less important. A final set is cognitive, based on previous technological developments and knowledge, and is institutionalized in the engineering profession and its organizations. Technology, therefore, differs from science in that it is oriented by all these nontechnical complexes.

Engineers attempt to bring together, work with, coordinate, manipulate, and build upon various elements of a technological system that include not only physical artifacts, but also social organizations, laws, financial and cost considerations, scientific theories, natural resources, and public perception. Scholar John Law (1987) coined the term ''heterogeneous engineers'' to cover his description of the way engineers seek to associate and manage these entities to build their technologies. This activity is as much a social and even political activity as it is a scientific or technical activity. Similarly, Michel Callon (1987), a French scholar of technology, depicted the engineer as a system builder, and he, together with several other authors, argued that technological development should be seen as the development of technological systems.

Thomas Hughes' study (1983, 1987) of electricity-generating systems was based on the idea of viewing a set of related technologies as part of a system. Hughes' technological system included physical artifacts such as turbogenerators, transformers, and power lines; organizations such as manufacturing firms, utility companies, and banks; scientific components such as publications, research programs, and university courses; laws; and natural resources such as coal mines. All these elements are interacting components of a system which the engineer attempts to bring together, coordinate, manipulate, and build upon (Callon 1987):

> Because components of a technological system interact, their characteristics derive from the system. For example, the management structure of an electric light and power utility, as suggested by its organizational chart, depends on the character of the functioning hardware, or artifacts, in the system. In turn, management in a technological system often chooses technical components that support the structure, or organizational form, of management. (Hughes 1987, p. 52)

Hughes' study served to highlight the many nontechnical aspects of technological decision making and development. In particular, he showed how political factors were critical to the acceptance of a new system. He pointed out that engineering textbooks often discuss only the technical components of a technological system, ''leaving students with the mistaken impression that problems of system growth and management are neatly circumscribed and preclude factors often pejoratively labeled 'politics' '' (Hughes 1987, p. 55).

Many would go even further and say that not only is technological system building a social activity, but the physical components of the system are also socially shaped. Engineers bring social values, ideologies, and assumptions about social relations to their work, and these, together with their interpretations of the social context, get translated into hardware design and configuration. For example, Langdon Winner, in an article entitled ''Do artifacts have politics?'' (1980), identified two ways in which artifacts can contain political properties. [He defined politics as ''arrangements of power and authority in human associations as well as the activities that take place within those arrangements'' (p.123).]

The first way Winner highlighted is when the invention, design, or arrangement of a specific technical device or system becomes a way of settling a dispute. As an example, he gave the very low overpasses on Long Island, New York, which were designed by Robert Moses deliberately to discourage the presence of buses that might carry poor and black people on his parkways. Similarly, he cites instances where machines have been introduced despite their lack of cost-effectiveness specifically to break the power of skilled worker unions.

Winner also gave an example of where a technical development has promoted the interests of some social groups while disadvantaging others. The mechanical tomato harvester allowed tomatoes to be picked and sorted automatically. Because the machine was rough on tomatoes, new types of tomatoes were bred that were stronger and more able to be machine handled, but were less tasty than previous varieties. The harvester reduced costs but was very expensive to buy. Only wealthy farmers, who could afford concentrated, large-scale tomato growing, found the harvester economical. Smaller farmers found they could not compete. As a result, more tomatoes were grown by far fewer tomato growers, and tens of thousands of jobs were destroyed. Winner argues that this is an example of technological innovation being introduced to favor the interests of large agribusiness concerns. In this way, the technology reinforces existing patterns of political and economic power.

A second way in which artifacts may be political, as identified by Winner, is when such technologies ''appear to require, or to be strongly compatible with, particular kinds of political relationships.'' He gives the atom bomb as an example of an inherently political artifact:

> As long as it exists at all, its lethal properties demand that it be controlled by a centralized, rigidly hierarchical chain of command closed to all influences that might make its workings unpredictable. The internal social system of the bomb must be authoritarian; there is no other way. (p. 131)

Similarly, David Dickson (1974) described the wider consequences of technological changes as resulting from the very nature of technology and the priorities and conscious motivations of those who design and implement technology. This contrasts with the more usual view that environmental and social impacts either arise from the misuse of technology or that they are the unintended consequences of it. The latter, more commonly held, view enables engineering practice to be seen as a neutral activity divorced from the social realm, whereas Dickson sees it as part of a political process.

The image of engineering as a purely technical activity has not only been perpetuated in engineering education but has been reinforced by the engineering community, which sought to increase its influence through emphasizing those aspects of technological decisions they are best educated to deal with. Many engineers felt that too much exposure of the social and political nature of technological decisions would threaten their role as experts and open up such decisions for public scrutiny.

Defining a problem as technical conveniently hides the political choice and priorities involved and reduces the arguments to arguments over technical details (Brooks 1965). In this way, the decision appears to be subject to objective criteria, which can be evaluated by the experts using economic and scientific models, calculations, and statistics (Nelkin 1984). Difficult issues such as conflicting interests do not have to be resolved, and the alternatives can be compared solely on the basis of cost and effectiveness in solving the immediate problem (Nelkin 1975).

By keeping issues confined to technical discussion, not only do policy makers avoid making their objectives and priorities explicit, but they ensure that any argument is confined to an arena in which experts have authority. If it is admitted that a decision has social and political dimensions, then it is much more difficult to maintain that only scientists and technologists should discuss and influence it (Sklair 1977). Proposals can be ''thrust upon the public as if they were noncontroversial technical decisions'' and without policy makers appearing to be arrogant or undemocratic in doing so without open debate (Nelkin and Pollack 1977). The justification of major policy decisions in terms of ''some purportedly objective knowledge'' is seen to be necessary in representative democracies (Albury 1983, pp. 6–7). Unspoken objectives such as winning votes in marginal electorates or attracting industry to a particular region do not become explicit. Opposition can then be labeled emotional or politically biased, ignorant, or irrational (Nelkin 1971).

It is not to be assumed that experts are fooled by the pretense that a problem is entirely technical. Most engineers are fully aware of the political dimensions of the decisions they make and the advice they give, but they cannot make those political dimensions obvious for fear of undermining the faith others have in their expertise. They must appear to be apolitical for, after all, they are not elected, and it is their perceived neutrality that allows them to have power. Guy Benveniste (1972), in his book *The politics of expertise*, claimed that ''a principle function of the apolitical definition of the policy expert's role is the exact opposite of the definition: it provides access to social power without political election'' (p. 65).

The portrayal of engineering and technological decision making as a purely technical activity served not only to disenfranchise the public with respect to technological development, but also to discourage many students from choosing engineering as a career. Often it was students with broader interests and a different range of talents who were put off; those who wanted to work with people rather than machines and numbers, those who cared about social issues. Too often it was the female students who were put off.

THE NEW ENGINEER

Engineers are now keen to throw off this image of a narrow technical focus and a disinterest in society. Increasingly, raising the status of engineering and the employability of engineers is seen to be dependent on fostering a broadened outlook. Bryan Thurstan (1995), writing in *Engineering Times*, argued that engineers, who have been criticized for being one-dimensional with a preoccupation for numbers and science, should be more willing to discuss nontechnical aspects of engineering projects:

> A greater recognition of non-engineering inputs would certainly heighten the profession's standing in the community. With the depth of skills the engineering profession has to offer, it would probably go a long way to raising the public's awareness of the role of engineers in society, and as a bonus would certainly enhance the profession's status.

Similarly, the 1995 president of the Institution of Engineers, Australia, Ian Mair, pushed for a broader definition of engineering that went beyond providing technical solutions to problems and involved engineers seeing themselves as having a role in defining problems and considering social and environmental issues. Engineers no longer ''consider themselves as technocrats behind closed doors,'' says Connor, Mair's successor; ''engineers are being challenged to think beyond their traditional role—and even beyond their traditional methodologies'' (Georg 1995, 1996).

Speaking at the launch of the new British Engineering Council last year, the Vice Chancellor of Cambridge University spoke of the need to make room in the engineering curriculum for arts subjects and extracurricular activities that ''provide an essential social broadening'' as well as communication and leadership skills. The Canadian Academy of Engineering's report *Engineering education in Canadian universities* similarly emphasizes the need for ''broader, less specialized, more integrated undergraduate programs with increased emphasis on design and social context.'' The U.S. Accreditation Board for Engineering Education has called for a ''general education component that complements the technical content of the curriculum'' (*Changing* 1996).

The U.S. report on *Engineering Education: Designing an Adaptive System* also calls for further incorporation of humanities subjects into engineering education. It stated that what is required is an engineering education system ''that is highly adaptable to the demands of the future, producing well-rounded professional engineers able to work together efficiently in teams to identify and solve complex problems in industry, academe, government and society.'' Engineering graduates, it envisages, ''will have greater intellectual breadth, better communication skills, a penchant for collaboration, and a habit of lifelong learning'' (*Engineering* 1995). These qualities will allow them to take on leadership and managerial roles as well as careers in other professions.

The latest Australian review of engineering education, *Changing the Culture*, calls for nothing ''less than a culture change in engineering education which must be more outward looking with the capability to produce graduates to lead the engineering profession in its involvement with the great social, economic, environmental and cultural challenges of our time'' (p. 6). Launching the report, Institution President Tom Connor said that ''The Institution of Engineers has long supported the review's call for a broader undergraduate education to include non-technical topics.''

Previous reviews of education have made the same calls, but there has been a tendency, in Australia at least, to take the view that what was required was more management education in engineering degrees. The social element of engineering was reduced down to how to manage people, rather than being able to understand the wider social issues inherent in the design, choice, adoption, and use of technology (''Interface'' 1996a). The latest review makes it clear that this is not sufficient.

Australia's Taskforce on Educational Programs identified the following skills and expertise that an engineer will require in the year 2010, in addition to those already supplied by a traditional engineering education:

- Have enhanced communication skills
- Provide significant leadership beyond the technology
- Be more innovative and creative
- Be better life-long learners and more adaptable to new learning situations
- Be better managers of people and systems
- Be more accountable for the results of their decisions within the total context of economic, political, ethical, cultural, and environmental issues
- Operate further within and across professions that are global
- Utilize quality improvement practices in all aspects of their work. (''Interface'' 1996b)

This will require a new approach to engineering education, because there is scarcely room for all the short-lived technical knowledge that universities have traditionally felt they must provide. The new approach will be more ''on learning how to learn'' and less on filling the students with the requisite knowledge. It will ''place greater emphasis on generic methodology, overall design, and generalized processes, systems integration, forward thinking, and management of change, rather than on specific expertise utilizing the current technology with short-term horizons.'' The latter can be acquired as necessary by the individual engineer through postgraduate courses, industry training, and self-learning (''Interface'' 1996b).

Changing the Culture also called for graduates with an ''understanding of and commitment to professional and ethical responsibilities'' (p. 30):

> For engineering graduates to take a more effective societal role, they must be better communicators. This means that, in addition to having the ability to explain technical prob-

lems, they must be politically and socially aware so that technical decisions can be made, understood and communicated, with sensitivity, especially across cultural boundaries. (p. 7)

This culture change in engineering education, it is hoped, will in time extend throughout the profession. Reform of education is merely the first step in a wider review of the future roles and responsibilities of engineers (''Minister'' 1997).

CONCLUSIONS

Engineering is an evolving profession that adapts to suit its context and the needs of the community. The current transformation to the new engineer is just such an adaptation, necessary to ensure that future generations will be served as well as past generations have been by the engineering profession. The new engineer is being demanded by employers, professional societies, the community, and engineers themselves, and engineering education will play an essential role in achieving the necessary transformation.

A new educational approach is needed to meet these changing requirements. A broader, more general approach is required that not only helps students to understand basic engineering principles but also gives them the ability to acquire more specialized knowledge as the need arises. But beyond this, there is also a need to provide young engineers with an understanding of the social context within which they will work, together with skills in critical analysis and ethical judgement and an ability to assess the long-term consequences of their work.

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