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2006

Lessons from transdisciplinarity studies in the design and evaluation of engineering education research

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Publication Details

Carew, A. L., Wickson, F. & Radcliffe, D. (2006). Lessons from transdisciplinarity studies in the design and evaluation of engineering education research. AAEE - Annual Conference of Australasian Association for Engineering Education (pp. 1-7). Auckland, NZ: Australasian Association for Engineering Education.

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Abstract

Engineering education research in Australia is a burgeoning field. The literature and theory on transdisciplinary research presents some valuable ideas for justifying, designing and evaluating engineering education research. Engineering education research is a transdisciplinary endeavour in both a literal sense (in that it draws on knowledge from the disciplines of engineering and education), and in a formal theoretical sense, given that transdisciplinarity is defined as problem solving through ‘the context specific negotiation of knowledge’. In this paper, we describe three outcomes that transdisciplinary research aspires to (problem-solving, peer approval, and mutual learning) and a case study of their application in shaping engineering education research. The case study details a research project titled ‘Teaching and Assessing Meta-attributes in Engineering: Identifying, Developing and Disseminating Good Practice’. This project commenced late in 2006 and is funded by the Carrick Institute for Teaching and Learning in Higher Education. This work is part of a much broader discourse globally concerned with research and scholarship in engineering education and its impact on the practice of engineering schools. For example, the ASEE has launched the “Year of Dialogue on Scholarship in Engineering Education” and the National Science Foundation in the US is conducting a series of Colloquy to determine the main research questions and themes in engineering education. As engineering education emerges as a discipline in its own right, we need to consider carefully the nature of knowledge in this field and how we acquire and share it.

Disciplines

Arts and Humanities | Social and Behavioral Sciences

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Lessons from Transdisciplinarity Studies in the Design and Evaluation of Engineering Education Research

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Abstract:

Engineering education research in Australia is a burgeoning field. The literature and theory on transdisciplinary research presents some valuable ideas for justifying, designing and evaluating engineering education research. Engineering education research is a transdisciplinary endeavour in both a literal sense (in that it draws on knowledge from the disciplines of engineering and education), and in a formal theoretical sense, given that transdisciplinarity is defined as problem solving through ‘the context specific negotiation of knowledge’.

In this paper, we describe three outcomes that transdisciplinary research aspires to (problem-solving, peer approval, and mutual learning) and a case study of their application in shaping engineering education research. The case study details a research project titled ‘Teaching and Assessing Meta-attributes in Engineering: Identifying, Developing and Disseminating Good Practice’. This project commenced late in 2006 and is funded by the Carrick Institute for Teaching and Learning in Higher Education.

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Emergence of Engineering Education Research

Globally there is growing discourse concerned with developing rigorous approaches to conducting research and undertaking scholarship in engineering education, and at evaluating its impact on the practice of engineering schools.

In 2005, the *Journal of Engineering Education*, published by the ASEE was re-launched as “the research journal for engineering education” (Lohmann, 2000). This journal has been in continuous publication for nearly a century. The shift from publishing articles that were descriptive to ones that are evidence-based and apply appropriate methodological approaches, signals an important step in the maturation of engineering education research and indeed the arrival of engineering education as a discipline (Becher and Trowler, 2001). While the new look journal finalises this change, the transition has been underway for at least a decade. The Special Issue of JEE published in January 2005 contained review articles that spanned most aspects of teaching, learning and assessment in engineering education. Other international journals on engineering education are also evolving in ways that reflect this shift to more rigorous standards of scholarship.

The evolution of the JEE to become a research journal reflects the emergence of a viable community of research scholars who are making engineering education a major part of their research profile (Baillie, 2003). This evolution addresses the issue of a lack of rigour in engineering education research and in evaluation of teaching innovation. However it begs the question, how does this research translate into ongoing improvement in engineering education practice? In part to address this issue, the “Year of Dialogue on Scholarship in Engineering Education”, was launched at the 2006 Annual ASEE Conference in Chicago. This is an attempt to engage a wider group of engineering education stakeholders, for example administrators, Deans, industry, professional bodies and regular engineering academics.

Driven by a concern to produce a diverse engineering workforce with the capability to meet the rapidly changing demands of global engineering practice and national competitiveness and security, the aim of the year is to debate the key issues and concerns associated with advancing scholarship in engineering. The objectives include developing the capacity for continual renewal rather than periodic reforms by adopting an approach that mirrors the broad research strategies that have been successfully applied to other engineering challenges. In other words, to underpin the whole engineering education enterprise – what we do, why we do it and how we do it - with appropriate research and scholarship. One approach that offers promise for engineering education is to revisit Boyer’s four-part conception of the work of academics as the scholarship of discovery (research), the scholarship of teaching, the scholarship of application and the scholarship of integration (Radcliffe, 2006).

Also in the USA, the Centre for the Advancement of Scholarship in Engineering Education (CASEE) with support from the National Science Foundation is conducting a series of Colloquy to determine the main research questions and themes in engineering education. This process has arrived at a draft set of five clusters of engineering education research as follows;

- *Engineering Thinking, Knowledge, and Competencies:* Research on what constitutes engineering now and into the future.
- *Socially-Relevant Engineering:* Research on how diverse human talents contribute to the social and global relevance of our profession.
- *Learning to Engineer:* Research on developing knowledge and expertise in practice.

- *Engineering Education Pedagogies*: Research on the instructional culture and epistemology of engineering educators.
- *Engineering Assessment Methodologies*: Research on, and development of, assessment methods, instruments and metrics to enhance engineering education.

These five clusters contain 18 more specific research themes.

It is worth noting that this scoping of engineering education research goes well beyond studying what happens in the classroom, about matters of teaching and learning. Indeed engineering education is a much broader concept, and this should be reflected in research in engineering education. The first three clusters are about the nature of engineering, now and in the future; about engineering expertise, practice and purpose. These clusters would include matters of value systems and ethics in engineering. While the third and four clusters are more concerned with topics we more instinctively associate with the term engineering education, they are not limited to what happens in the classroom but include aspects of the wider enterprise including the educators themselves.

Engineering education research is also emerging in Australia. At the current time, there is strong support for evidence-based approaches to improving teaching and learning in Australian universities generally (eg. Australian Universities Quality Assurance process, and establishment of the Carrick Institute for Teaching and Learning). For engineering education, Engineers Australia's updated accreditation process implemented in 2000 is supporting the development of an evidence-based approach to assuring the quality of our courses and our teaching. The accreditation criteria represent a move away from the former predominant focus on the operating environment *per se*, toward a greater interest in the learning outcomes that discernibly result from the operating environment. In other words, Engineers Australia are increasingly focussed on the *outcomes* of teaching activity (ie. demonstrable student learning), rather than on the teaching activity itself. As such, the accreditation process has become more student-focussed in that faculties are required to "monitor, using declared performance criteria, the attainment of the targeted educational outcomes for the program" (EA, 2006, pg. 6). This requirement for evidence of student learning has helped drive the discipline to take more deliberate evidence-based approaches to improving teaching and learning, and reinforces the shift in the Australian HE sector toward researching teaching.

Researching across the Disciplines

Given strong drivers for researching engineering education, it is timely to consider modes of research that might influence or shape our efforts. Some of the current engineering education research effort is committed to theorising practice. Researchers at the forefront of this effort tend to import theories and methods out of the education arena and apply them in engineering. The past decade has seen an increasing use of educational theoretical frameworks to justify or explain innovation in approach to designing learning tasks, approaches to teaching and rational for assessment regime. Popular educational theorists used by engineering education researchers include: Biggs (Biggs, 2003), Piaget and Perry (Wankat and Oreowicz, 1992), and Kolb (Felder and Brent, 2005).

Beyond theorising practice, the group of researchers is emerging who specialising in empirical research on engineering education. Wankat and others (2002) have characterized the engineering context as difficult for engineering education research particularly given the epistemological divide between the engineering research culture and methods (the received view is of engineering research as post-positivist and quantitative), and the culture and methods of teaching research (often constructivist and methodologically plural). For engineering educators conducting research on teaching, it is necessary to cross the disciplinary and epistemological divide that distinguishes engineering research and educational research. This means that engineering academics new to educational research need to move away from an accustomed approach to research that is often numerical, where the researcher is mostly viewed as an objective observer situated outside the research, and where questions can be answered with some degree of statistical surety. Engineering education research more often requires an approach which asks questions that are often unable to be answered numerically, where the researcher is usually an interested participant in the research context, and where interpretation and representation plays a much more formative role in research outcomes. Engineering education researchers thus straddle a distinct disciplinary research divide, the divide that separates the quantitative research tradition from the qualitative.

We have argued that engineering education researchers are crossing disciplinary boundaries to meld theory and/or develop blended research practice for the emerging discipline of engineering education. This discipline crossing is a challenging task but offers potential for strong composites to inform our teaching, however, more is on offer. There is an emerging body of literature that discusses and develops various additional modes of boundary crossing in research. One of these modes, which could be a next step for engineering education research, is known as ‘transdisciplinarity’. Transdisciplinarity has been defined as problem solving through ‘the context specific negotiation of knowledge’ (Lawrence and Despres, 2004). This definition and related literature and theory on transdisciplinarity offer some potentially valuable ideas for justifying, designing and evaluating future research in our field.

Transdisciplinary Research

Transdisciplinary (TD) research is ‘context specific’. The notion of context in Lawrence and Despres’ formal definition of transdisciplinarity, refers to the way in which TD research focuses on a contextualised research problem; that is, a ‘real-world’ problem that is manifest and pressing within a specific social and/or environmental context. Importantly, one of the broadly agreed aims of transdisciplinary research is to offer practical solutions to these complex problems and to therefore bring about some degree of change in the selected problem context. Current engineering education research appears to cohere with this first tenet of TD research in that the primary focus of current research efforts appears to be the resolution of teaching and learning problems that are observed or emerge from the real-world of the engineering classroom or faculty.

Transdisciplinary research involves a ‘negotiation of knowledge’. The negotiation of knowledge is a process of eliciting and integrating a wide range of sources of information and input. While other forms of cross-disciplinary research (i.e.

multidisciplinary and interdisciplinary approaches) involve some negotiation between bodies of knowledge from different disciplines, transdisciplinary research is characterised by an additional mandate to negotiate beyond disciplinary knowledges. This means that in addition to drawing on and combining knowledge from a range of disciplines, transdisciplinary researchers tend to go beyond academe to consult and consider stakeholder perspectives, to draw on the experiential knowledges held within the community of stakeholders inhabiting the selected problem context. This means that for TD research, the negotiation of knowledge requires the 'intentional involvement of stakeholders in the definition of problems and those criteria, objectives and resources used to analyse and resolve them' (Thompson-Klein, 2004). This infers that transdisciplinary engineering education research would seek input from key stakeholders in the education on the next generation of practitioners (eg. industry, students, community groups, institutional management and administration, Engineers Australia).

A third characterising feature of transdisciplinary research implicit in the formal definition is that the method by which it is conducted calls for the interpenetration or integration of different epistemologies in response to the evolving needs and understanding of the problem in its context (Wickson et al. in press). For example, for the field of engineering education this may manifest as a need to develop methods that fuse quantitative and qualitative approaches to research. Interestingly, this position aligns with Engineers Australia's stated ideal for the assessment of graduate capabilities as described in the accreditation summary. "Each graduate capability target should ideally include measurable performance indicators to provide a basis for monitoring the level of attainment. The multidimensional performance metric in each case is likely to involve quantitative and qualitative measures with inputs from a range of sources" (EA, 2006; pg 8).

A focus on a contextualised research problem, collaboration and negotiation across and beyond disciplinary knowledges and the crafting of a shared and epistemologically integrative research method are all important features for the practice of quality transdisciplinary research. While this description may suggest that transdisciplinary research is somewhat complex or overly abstract for engineering education research, a useful, and perhaps more concrete way to envisage this form of research is in terms of the outcomes it aspires to.

Outcomes of TD Research

Transdisciplinary research aspires to three categories of research outcomes. We have labelled these: problem solving, mutual learning, and peer approval (Carew and Wickson, in prep).

The outcome of problem solving requires that the research has made a demonstrable contribution to solving a manifest, contextualised problem. This connects with the way in which a focus on real-world problems is a defining characteristic of transdisciplinary research (Wickson et al., in press). In the literature, this criterion is variously termed 'product outcomes', 'relevant knowledge', and 'balance'.

The second outcome aspired to in transdisciplinary research is mutual learning. The idea of mutual learning is that all parties to the research (eg. primary researcher/s, academic and industry collaborators, stakeholders and lay persons) experience some transformation of their understanding of the research problem, the problem context, their existing knowledge, and processes and possibilities for researching and resolving the problem. Of the three categories of outcome, this idea of mutual learning most clearly differentiates the objectives of transdisciplinary research from a simple combination of pure research (allied with peer approval outcome), and applied research (allied with problem solving outcome).

The third outcome of peer approval conforms with a traditional disciplinary approach to judging research quality. Becher and Trowler (2001) list mechanisms for peer approval as things like scholarly/journal publication, conference participation, disciplinary status, citation. In the field of transdisciplinarity, authors describe this criterion as: ‘consistency with multiple separate disciplinary antecedents’ (Mansilla et al., pg. 3). In other words, in addition to solving problems and generating mutual learning TD research aspires to build the disciplinary knowledge base upon which it draws (i.e. contribute outcomes acceptable to the fields of engineering and education).

We have explained the distinguishing characteristics of a transdisciplinary approach to research and the related outcomes this approach aspires to. We now provide an example of a particular engineering education research project designed with these principles in mind.

Application to Engineering Education Research Design

Early in 2006, the authors of this paper and a group of interested others crafted a proposal for engineering education research framed on the characteristics and approaches of transdisciplinarity. The research proposal was titled ‘Teaching and Assessing Meta-attributes in Engineering: Identifying, Developing and Disseminating Good Practice’ and was granted funding under the Carrick Institute for Teaching and Learning in Higher Education’s competitive grants scheme. The Project commenced late in 2006 and focused particularly on fostering the teaching of reflective practice and systems thinking at undergraduate level. We describe it here as an illustration of the way that transdisciplinary theory might shape and be shaped by engineering education research.

A problem-in-context

The Project addresses a problem that is pressing and manifest in the contemporary Australian engineering education sector. Engineering faculties across Australia are experiencing substantial pressure from industry, the professional body and their home higher education institutions to contextualise and embed graduate attributes in undergraduate programs. Responding to this pressure is proving challenging with three inter-related problems evident in the engineering education literature and familiar to most of us:

- Innovation is isolated and shortlived - much innovation in teaching engineering graduate attributes is at the level of subject, and driven by lone

academics working in isolation from peers and the pertinent literature. This means good practice rarely benefits from the; insights and critique of interested others, existing graduate attribute research and T&L theory.

- Rigorous evaluation is rare - few reported innovations in teaching engineering graduate attributes are evaluated in terms of their impact on student learning, and assessment of graduate attributes is considered problematic in the engineering literature. The current approach to quality assurance in HE is outcome focussed, and so these problems with evaluation and assessment undermine engineering educators' capacity to define, gather evidence on and discuss what works in teaching graduate attributes in engineering.
- Contextualisation is limited - the engineering graduate attributes described in the literature tend to be disproportionately aligned with generic institutional lists, and poorly aligned with the realities of engineering practice, particularly with design, which is central to engineering work. Discourse, research and development are needed to embed design-relevant meta-attributes (eg. reflective practice, systems thinking) in undergraduate engineering.

Negotiating knowledge

Negotiating knowledge requires engagement of a range of stakeholders in shaping the research approach and deciding outcomes, and the intentional integration of diverse knowledges from within the problem context and from across the disciplines. The Project will negotiate knowledge about good practice in the teaching and assessment of meta-attributes in engineering in two ways. Firstly, knowledge on the problem and its potential solutions will be negotiated through extensive and ongoing consultation with key stakeholders (eg. Engineers Australia, ACED, industry bodies, engineering academics, students); via a literature and practice review; and, where necessary, through structured empirical research with engineering students and academics. This consultative phase will lead into outreach and PD activities for engineering academics and academic developers (eg. regional forums, opportunistic outreach). Secondly, knowledge will be negotiated within the project by establishing a cross disciplinary leadership group to guide the work and learn through active participation. This group will link and develop: recognised innovators in the field, engineering education change agents, academic developers, outstanding engineering educators, and accreditation expertise from Engineers Australia.

Responsive research method

A responsive research method requires that the research attempts to integrate epistemologies, for example, reconcile the post-positivist (usually quantitative) with the constructivist (more often qualitative) or more generally positivism with interpretivism. Additionally, the research method should evolve in response to the research problem-in-context. In the project under discussion, the potential for responsiveness is built in through early and ongoing engagement with a range of stakeholders, and the potential for epistemological integration is supported through engagement and ownership by a cross disciplinary leadership group. Frankly, this element of transdisciplinarity is difficult to envisage and offers a challenge for research design because the precise way in which research will need to be responsive is difficult to predict (given we have not yet spoken with stakeholders and given the somewhat unknown quality of the as-yet unsurveyed problem context).

Transdisciplinary outcomes

The intention of the research is that it will deliver three types of outcome: problem solving, mutual learning and peer approval. Table 3 summarises the problems the project will address, the mechanisms employed and expected deliverables.

Table 1. Summary of project problems, mechanisms and deliverables.

	Problem Solving Objective	Mutual Learning Objective	Peer Approval Objective
Problem	Dissemination of good practice in T&A engineering meta-attributes	Development of national leadership capacity for T&A meta-attributes	What works in T&A engineering meta- attributes?
Mechanisms	University-based Regional Forums for engineering academics	Active engagement of leadership group. Guided reflective interviews group	Qualitative & quantitative research with students
Deliverables	Documentary resources, heuristics & examples of good practice. PD & links b/w eng academics & faculties.	Development of distributed leadership group for teaching and assessing engineering graduate attributes	Scholarly publication & conference presentations on all three outcome categories.

The overall change we are attempting to generate is better teaching and assessment of reflective practice and systems thinking in Australian engineering programs. The problem solving element aims to support the contextualisation, teaching and assessment of these meta-attributes in undergraduate engineering programs. We are aware that there currently exist pockets of good practice, and so the challenge for this project is to investigate, document, improve and disseminate examples of good practice, and to do this in a way that enables individual engineering academics and faculties to embed these approaches in their subjects and programs. Evidence of effective problem solving would include such things as: changed teaching and assessment practice amongst participating engineering academics; Engineers Australia accreditation visits noting or recognising better practice in participating institutions; and a shift in the Australian engineering education literature toward reporting longer lived innovation in teaching attributes, more rigorous evaluation of such teaching and more robust contextualisation of attributes in engineering faculties.

The mutual learning outcome will primarily be delivered through establishment of the leadership group. This group will be formed on a theoretical framework adapted from Lave and Wenger's ideas on community of practice and situated learning (Lave and Wenger, 1991). In Figure 1, members of the cross disciplinary leadership group are depicted as members of one of two broad communities of practice ('academic development' and 'engineering education'). The central, emergent community of practice depicted in Figure 1 is termed 'TLA in Engineering' and represents the creation of a new community that draws on the knowledge, experiences and approaches of each of the original two communities of practice. Figure 1 depicts this project as an opportunity for participants to share in and learn from cross disciplinary discourse within the group, to shape and learn from the research approach and outcomes, and to further develop the community of practice and discourse within their own home institutions and existing networks. The primary mechanism to foster

this new community of practice will be through engagement in the authentic learning task of this project.

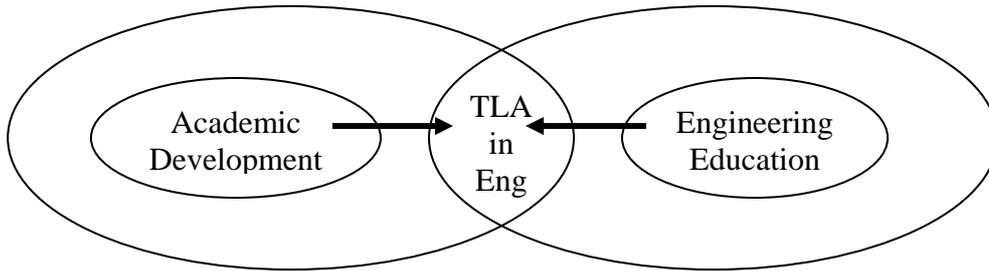


Figure 1. Teaching, Learning & Assessment in Eng. as an Emergent Community of Practice

Peer approval outcomes will emerge as a result of formal empirical research and scholarly publication. An area of enquiry suggested by our initial literature review is the development of authentic assessment approaches, and the related importance of constructive alignment (Biggs, 2003) for structuring and communicating such assessment at both subject level, and for substantiating program-wide attainment of meta-attribute learning. Constructivist researchers in higher education have demonstrated a relationship between what teachers think and do, and how and what students learn (Biggs, 2003). This body of research underpins an approach to research and evaluation which takes students' learning and experiences of learning as its primary metric. This theoretical framework suggests that an investigation of what works, for example, for assessing engineering students' meta-attribute learning should start by probing students' experiences of learning about and being assessed on, the target meta-attributes.

Concluding Remarks

As described earlier, the Centre for the Advancement of Scholarship in Engineering Education (CASEE) and US National Science Foundation have started a process of identifying the main research questions and themes in engineering education. They have nominated five draft clusters and the Project we described above falls across two of the research clusters (Engineering Education Pedagogies & Engineering Assessment Methodologies). While the outcomes of our research on teaching and assessing reflective practice and systems thinking in engineering may contribute insights to these nominated themes, it is the *process* of doing the research that is likely to contribute most to the field. This is because the theoretical foundation of transdisciplinarity upon which the research is based commits us to researching in an intimately contextualised and responsive way. Further, the TD philosophy has led us to shape and attempt research that intends to generate and document three distinct outcomes: solving an engineering education problem; mutual learning between engineering educators and educational developers; and peer approval of the research by scholars in both the engineering and education research sectors. It will be very interesting to see in what way and how well these objectives are met, and to learn from the challenges that will influence how such a project pans out.

As engineering education emerges as a discipline in its own right, we need to continue to consider carefully the nature of knowledge in this field, what sort of questions warrant investigation and how we might acquire and share insights on engineering

education. In this paper we have described an approach to research that differs from our accustomed approaches in engineering discovery research, but that perhaps makes sense for engineering education research. Changing the teaching practice and philosophy of engineering academics, engineering faculties and the accrediting bodies requires a strongly contextualised and democratised approach. This is because recipients of innovation who have had little hand in shaping their new direction are notoriously (and unsurprisingly) resistant to change. While our theoretical description of the conditions of transdisciplinarity may seem like a tall order, this may simply be a pragmatic way to ensure our engineering education research efforts generate outcomes that prove more valuable to the sector than research quantum.

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