Interdisciplinarity as a path to inclusivity in the engineering classroom: a design-based research approach

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Abstract*: Engineering as a professional practice frequently involves multifaceted, interdisciplinary teams addressing complex problems. Consequently there is increasing demand on engineering education, which is often constrained by strict discipline boundaries, to equip students with the necessary competencies to contribute effectively in multidisciplinary contexts. This paper introduces one approach to reducing these boundaries and describes the theoretical basis for, and the design of, an interdisciplinary project-based subject presented at third year level, where students from a range of disciplines worked together on a real-world project. It addresses some of the challenges and issues experienced and discusses possible ways forward in introducing interdisciplinarity into an engineering curriculum.*

Introduction

Engineering as a professional practice increasingly involves multifaceted, interdisciplinary teams addressing complex problems. This means in turn that the demands made of 21st-century engineers are considerable: engineers must be technically competent, globally sophisticated, culturally aware, innovative and entrepreneurial (Clough, 2004) as well as nimble, flexible and mobile (Felder, 2006).

As Sheppard *et al* (2008) suggest, new paradigms for engineering education are required to:

1. accommodate the ever-increasing pace of intellectual change (e.g., from reductionism to complexity, from analysis to synthesis, from disciplinary to multidisciplinary and beyond);
2. develop, apply and exploit new technologies (e.g., from the microscopic level of info-bio-nano- to the macroscopic level of global systems);
3. integrate a far more holistic approach to social needs and priorities, linking social, economic, environmental, legal, and political considerations with technological design and innovation;
4. reflect in its diversity, quality, and rigor the characteristics necessary to serve a 21st-century nation and world.

Thus teaching engineering for the 21st century requires transforming the classroom from one focused on "facts, formulas, and algorithms for solving well structured closed-ended single discipline problems", centred on "lectures, textbooks and objective tests", and assuming that "all students are basically alike" (Felder, 2006) to one focused on interdisciplinary inquiry. This is not an easy process, and there are very few examples of interdisciplinary engineering pedagogy to guide us.

Interdisciplinarity has been defined in a variety of ways (see, for example, Klein, 1990; Lattuca, 2003) but they are all underpinned by a philosophy of inclusivity. Fundamental to inclusivity is the principle of collaboration and therefore engagement with the topic at hand *as a team*.

To encourage students in interdisciplinary exploration of a complex system and to develop their collaborative skills, an interdisciplinary subject was developed that has brought together third year students from a number of faculties. The subject was developed using a design-based research (DBR) approach.

This paper presents our experience with introducing this subject. It describes the DBR methodology that was adopted and presents the findings and insights that have arisen from the process thus far. It is important to note that this is a work in progress and represents only the first steps in an iterative process: further refinement, arising from running the subject several times, is anticipated.

Leading in a Complex World – Overall Subject Outline

The subject we have developed is a third year project-based subject entitled *Leading in a Complex World*. The main learning outcome of this subject is to develop the skills required to lead change within a complex system. This is a fundamental graduate attribute for this institution and for Stage I competency as a professional engineer (Engineers Australia, 2011). The overall aim of the subject is to investigate a complex system from the perspectives of the stakeholders involved, and through various disciplinary lenses, using a collaborative team-based approach.

This subject was presented as one of the University of Melbourne's "breadth" subjects, which form part of the new Melbourne Model introduced in 2009 (The University of Melbourne, 2010). By their nature, breadth subjects are multidisciplinary and open to enrolment by students from any faculty, not just engineering. Breadth subjects are intended to provide students with broader perspectives that will equip them with graduate attributes necessary for responding to a world of ever-increasing complexity.

Leading in a Complex World was taught over a 12 week semester as a weekly 4 hour workshop session in which students worked in small teams to explore a complex system. The students who enrolled in the subject came from a range of "home" disciplines, including engineering, science, environments, commerce and arts (politics, history, criminology). The overall educational paradigm used was **project-based learning** with an intense focus on ***process***. Content, in the form of either catalytic questions or expositions of theory about such topics as leadership, complexity, teamwork and self-directed learning, was provided progressively throughout each session, followed by activities designed to facilitate active engagement. Active face-to-face participation in class was mandatory.

The initial design of *Leading in a Complex World* drew on our experience in project-based learning. The subject was intended to provide students with an opportunity to explore complex real-world systems and to develop proposals for initiatives they might take to bring about changes they have identified. This year, the complex system chosen for investigation was Megacities. Students self-selected into teams based on specific "Topics of Engagement" (ToE), such as transport, population growth, micro-communities, and environmental impacts, all of which were chosen by the students.

These ToEs served as a framework for addressing the question "How would I lead change in one or another element embedded within a complex system?" There was no right answer, and it was vital that students actively engage with the process of inquiry and their own interests.

Once the ToEs were identified, the overall process adopted was as shown in Figure 1. In their teams, students brainstormed who the various stakeholders might be. As individuals, they then chose a particular stakeholder and undertook on their own a deeper analysis of stakeholder interest, impact and influence on the system represented by topic at hand. Reconvening in their teams, students pooled their findings and began to explore the relationships and dynamics between the various stakeholders. At this point, students were able to review, and if necessary amend, the "change" they wanted to initiate.

The second phase of the process involved an exploration of the ToE from the perspective of various disciplines. The intention was that students would begin to investigate the disciplinary questions and methods of inquiry in relation to the ToE, based on their own disciplinary training. Further, by collaborating with students from other discipline domains, they would begin to appreciate the different lenses through which the ToE could be viewed.

After integrating their insights and experience as a team, students developed a final (team) proposal for the change they intended to lead. The whole process is summarised in figure 1 below.

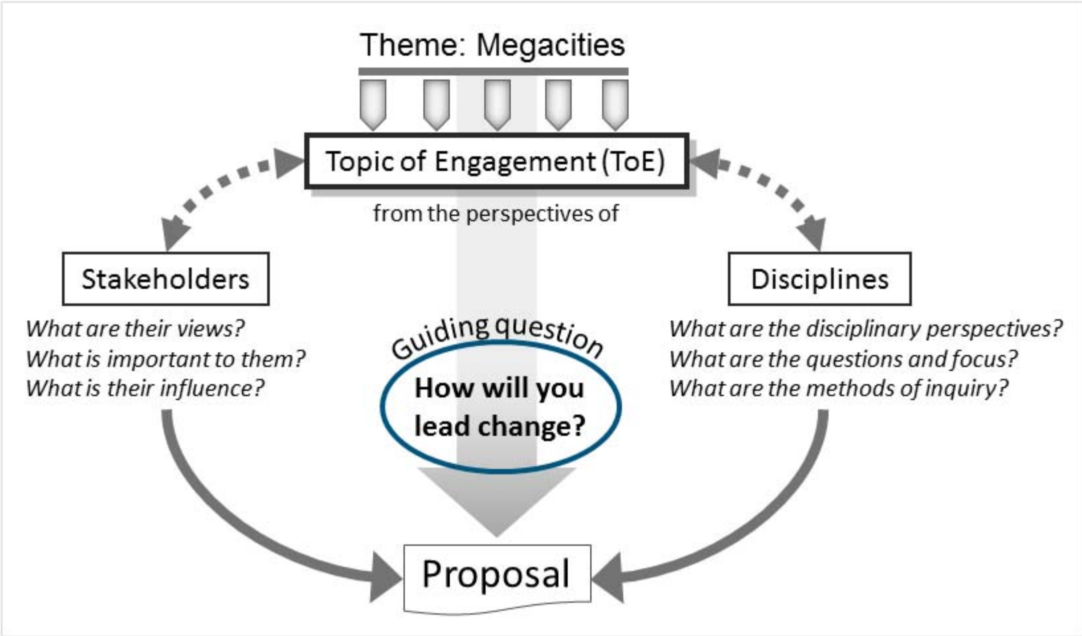

Figure 1: The project process adopted for the subject *Leading in a Complex World*

Student summative assessment comprised participation (20%), weekly reflective writing (20%), stakeholder analysis (20%), analysis of ToE from different disciplinary perspectives (20%) – all of these were submissions by individual students – and a final project report prepared collaboratively by each team (20%).

A Design-Based Research Exploration

This subject is still a "work-in-progress". Not only is the design of the subject evolving, but as it proceeds it evokes questions and provides insights that require further research. This is an ideal setting for the application of design-based research (DBR).

DBR (Edelson, 2002; Bell, 2004; Middleton et al, 2008; Wang and Hannafin, 2005) is a pragmatic research approach to the design and enactment of teaching interventions, grounded in theory and committed to delivering outcomes that are constructed in real-world contexts. It is a practice-based, embodied and lived methodology. Further, DBR possesses four fundamental attributes that are important for the task in hand – it is interactive, iterative, flexible, and builds theory.

In contrast to laboratory experimental research, DBR is applicable where multiple variables are involved, where the control of those variables is difficult or unlikely and where quantitation is difficult or even illusory. Nevertheless, the aim of DBR is to provide a body of evidence in support of theory. Despite its similarity to many engineering design processes, DBR has not as yet been widely used in engineering education research.

The methodology as we have applied it in developing *Leading in a Complex World* is summarised in Figure 2.

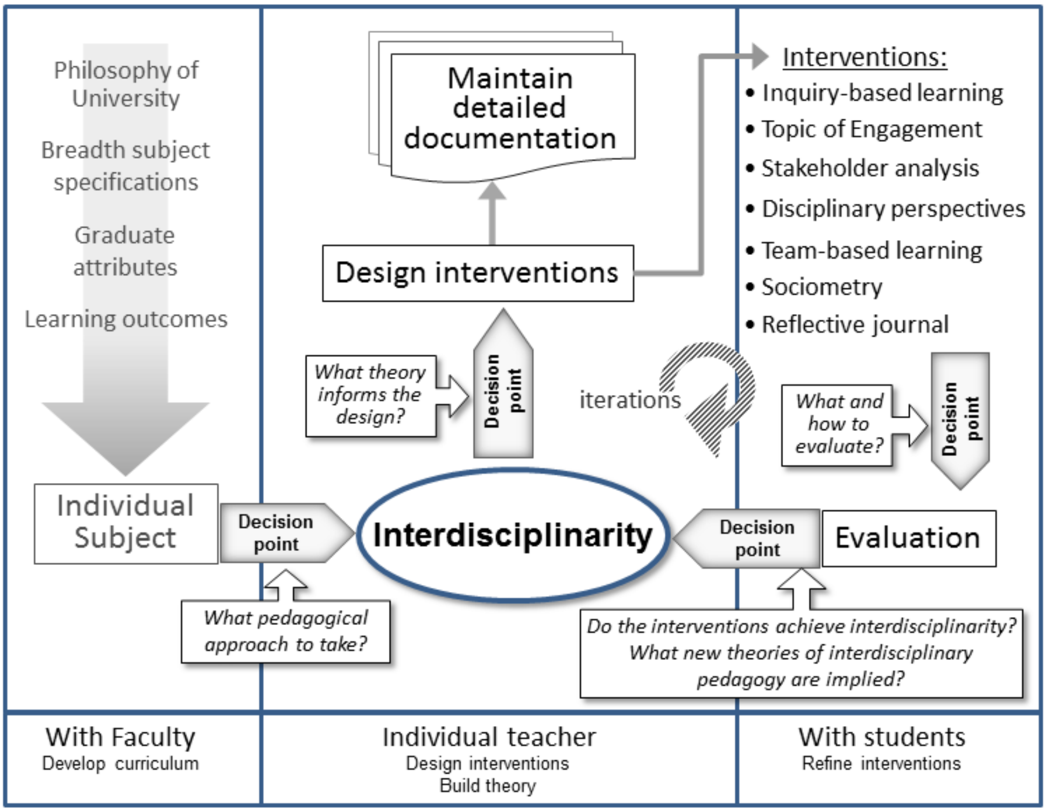

Figure 2: The design-based research and development process

Figure 2 shows a number of important features. The first thing to note is that there are three main components or phases, with the individual teacher playing a role in each:

1. the *teacher working with faculty* phase, which establishes the context for a subject, aligning the learning outcomes with the philosophy of the university, the breadth subject specifications, the overall curriculum, the desired graduate attributes, and the specific learning outcomes;
2. the *teacher / individual engineering education researcher* phase, in which the interventions aimed at achieving the desired outcomes are designed and documented, and a particular educational theory identified (in this case interdisciplinarity); and
3. the *teacher engaging students* phase, in which the interventions (in this case designed to bring about interdisciplinary learning) are 'trialled', their effectiveness evaluated, further refinements or modifications proposed, and new insights into the theoretical underpinnings of the intervention gained.

Our fundamental question was how do we develop learning outcomes that reflect interdisciplinarity, and what indeed does this mean? Notwithstanding the scope of DBR and the framework shown in figure 2, our purpose in this paper is to focus specifically on the intervention applied in the first iteration of this course with a further focus on how they might facilitate interdisciplinarity and inclusivity.

As a first step towards engaging with this question, the following interventions were designed:

1. Inquiry based learning – questions are the driving force behind inquiry-based learning and are essential if students are to gain any appreciation of other points of view. "Inquiry" was the underpinning philosophy throughout this subject – one of the principle activities in any session was discussion groups aided by butcher's paper and an abundance of pens!
2. Topic of engagement – this served as a practicable point of entry into engagement with a real-world complex issue;

3. Stakeholder analysis – exploring who the stakeholders might be in a particular topic, what their needs are, what values are held as important and what influence any given stakeholder has on the system – proved to be a powerful approach to understanding the complexity of the topic. Students had to grapple with the reality of how to acknowledge, include and integrate and views which frequently appeared diametrically opposed.
4. Disciplinary perspectives – students were required to explore the topic through the lenses of different disciplines, to ask what questions were important, what methods would be applied and data gathered to arrive at an understanding.
5. Team-based learning – critical to inclusivity is the ability to work closely and effectively with others who have different skills, perspectives, learning styles, imperatives, agendas, interests and motivation. Working in self-selected teams was a core component of this subject.
6. Sociometry. Sociometry uses a range of action techniques to reveal, and enhance, positive relationships within a group (Evans, 1962; Yang & Tang, 2003). Understanding these relationships and making the invisible visible so that everyone can see what is happening within the group is essential to effective group performance.
7. Reflective journal. Reflection lay at the heart of the learning process in this subject (Schön, 1983; Blockley, 1992). Students were required to keep a weekly reflective journal: an assessable element was that they were required to write a critique of their reflections at weeks 6 & 12.

Insights So Far …

Despite their innate curiosity and enthusiasm, many students had difficulty with inquiry, particularly with the concept that there was no right answer, or even a prescribed body of knowledge, in relation to the topic. Chaos emerged mid-semester, as students shifted to taking ownership of their own learning, but as this became established and they "got it" the delight was palpable. Open-endedness was one cause of uncertainty, and students had difficulty appreciating that process was more important than product or content. As Klein and Newell (1998) assert, "achieving synthesis requires proactive attention to process", but this was a concept foreign to most students and took considerable time to be accepted. Nevertheless by the end of semester "the big picture" became clear.

One of the striking features of the student initial exploration of stakeholders was their tendency to arrive at gross stereotypes or caricatures. It was apparent that many students had no appreciation of real-world stakeholders outside their own social or life experience. In future iterations of this subject we propose to engage students with real-world "living" examples of stakeholders. It is important that students have the opportunity to speak with real stakeholders, either by conducting their own interviews or through pre-arranged guest speakers.

Student engagement in disciplinary perspectives surprised us. Not only did they have difficulty in articulating the views of "other" disciplines, they were unable to speak with any authority from their own disciplinary perspective, or even engage in discussion about what "discipline" meant. For the future, because interdisciplinary investigations involve multiple research methods and literatures, we are proposing to spend considerably more time in discussing how disciplinary knowledge is created. There is also a need for greater emphasis on course materials that relate to the question "What does it mean to be a practitioner in my discipline and how do I acknowledge other disciplinary views?" This relates to the issue of negotiating interdisciplinary identities raised recently by McNair *et al* (2011).

An unexpected consequence of the range of disciplines represented by the class was that team work could not be taken as a given – a significant proportion of the class had *never* worked in a team! This observation bears out Austin and Baldwin (1991) who reported that while collaboration is almost the norm in the physical and natural sciences, it is not widespread in the humanities. In future, we expect to spend more time and effort on team development.

Leading in a Complex World is in a sense an "experiment" in enhancing inclusivity. The interventions introduced so far show promise in rendering accessible learning about complexity for which there is no "right" answer. Our experience suggests that the extent of understanding is directly related to the number of disciplinary perspectives that are explored, while analysis of stakeholders reveals social context, dynamics and values. Containing the conflicts that are inherent in complex systems, and hearing the voices of those who normally go unheard requires the development of teams in which robust and lively discussion is possible. These principles will be guiding our efforts in repeating this subject over the next few years.

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