Invited Paper - Improving First-year Engineering Education Using the Engineers Without Borders Australia Challenge: what worked for whom under what circumstances

Ms. Lyn Brodie, University of Southern Queensland

Lyn Brodie is an Associate Professor in the Faculty of Engineering and Surveying at the University of Southern Queensland. Her research interests include engineering education, Problem Based Learning, assessment and the first year experience. She is a board and founding member of the USQ Teaching Academy and Director of the Faculty Engineering Education Research Group. Lyn was the academic team leader for the teaching team which successfully designed a strand of PBL courses for the faculty. Her work has been recognised through several awards including a University Award for Design and Delivery of Teaching Materials, Carrick Institute Citation and Australian University Teaching Award for Innovation in Curricula Learning and Teaching, USQ Associate Learning and Teaching Fellowships for curriculum and assessment development and recognition from the Australian Association of Engineering Educators for innovation in curricula. On several occasions Lyn has been a visiting Professor to the University of Hong Kong – Centre for Advancement of University Teaching, consulting in both PBL and online curriculum development and assessment. She is the 2013 president for the Australasian Association for Engineering Education (AAEE).

Lesley Jolly, Strategic Partnerships

My original work as an anthropologist was with Australian indigenous peoples but in 1996 I was approached to undertake an ethnography of the first-year engineering class at the University of Queensland with a view to understanding the gender dynamics there. Since then my association with engineers and engineering has grown to dominate my research life. I have continued to pursue my contact with engineers through a variety of research projects, the supervision of PhD students in engineering problems that have social dimensions and by establishing and leading the new Research Methods Interest Group of the Australasian Association for Engineering Education (AAEE). In that capacity I have run workshops on research methods and educational evaluation in Australia and New Zealand and was a founder leader of the annual AAEE Winter School for engineering education research. In the last two years I have completed two CRC projects; Evaluation of Simulators in Train Driver Training and Towards a National Framework for Competence Assurance for Train drivers. I have also recently managed an ALTC project called Curriculum Change through Theory-Driven Evaluation on behalf of the University of Queensland.

Caroline Crosthwaite, University of Queensland

Caroline Crosthwaite BE(Hons), MEngSt (UQ), MSc. (JCU). Caroline is Associate Dean (academic), Faculty of Engineering, Architecture & Information Technology at the University of Queensland (UQ), Australia where she oversees teaching and learning, international partnerships and pathways, and academic and student administration in coursework programs. Caroline is a chemical engineer and has worked at a number of Australian Universities where she has been led curriculum design and the development of student centred, active learning practices. Caroline coordinated UQ's chemical engineering curriculum team that implemented the internationally recognised Project-Centred Curriculum in Chemical Engineering which in 2005 won the Australian Award for University Teaching for Enhancing the Quality of Teaching and Learning. Caroline's engineering education work has also been recognised with an Australasian Association for Engineering Education Award for Excellence in Curriculum Innovation (2003) and the UQ Vice Chancellor's Award for Internationalisation (2010). Caroline has also been involved in the development of international partnerships including the first Australian - French and Australian - German double degrees in engineering. She has just completed a national project looking at the use of Engineers without Borders projects (EWB Design Challenge) in the engineering curriculum in thirteen different Australasian universities. Caroline has also been involved in previous teaching and learning projects developing immersive learning environments using virtual reality, and supporting and assessing students in project teams. Caroline consults nationally and internationally on engineering education. She has worked with Imperial College London, Technical University of Denmark, Purdue University, Institution of Chemical Engineers (Australia), and (Malaysia).

Lydia Kavanaugh, University of Queensland

Associate Professor Lydia Kavanagh is an innovative, enthusiastic and dedicated teacher and mentor who brings to her discipline a wealth of professional engineering experience. Since returning to academia in 1998 after working for 13 years in industry, she has become a leader in engineering education in Australia and has used her background as a professional engineer to design both curricula and courses for active learning by combining real-world projects and specialist knowledge. As UQ's Director of First Year Engineering, Lydia has inspired students to develop the knowledge, confidence and capabilities essential for success in the engineering profession in the 21st Century. She is dedicated to ensuring that they not only learn about engineering but also how to be engineers. In 2011, she won a national award for Excellence in Teaching, and in 2012, her first year engineering courses received a commendation from Engineers Australia.

Improving First-year Engineering Education Using the Engineers Without Borders Australia Challenge: what worked for whom under what circumstances.

Introduction

Reviews of engineering and engineering education around the world [1,2,3,4] have called for engineers to rise to the challenge of a global environment characterised by rapid social, environmental and technological change. However, despite changes to curriculum intended to pursue such goals the most recent review of engineering education in Australia[5] notes that "further curriculum changes and developments will be essential to maintain student numbers and meet students' expectations satisfy employers [*sic*] and the profession at large" (p.59). The report goes on to note that "current engineering curricula [around the world] do not deal well with the difficult topics of uncertainty, integration and complex systems" (p.62) and multidisciplinary approaches (p.72). Other areas of the curriculum in need of change include the need for active learning, inclusivity, relevance to current engineering practice and better integrated project management instruction[5].

One response to such demands has been the adoption of the Engineers Without Borders Challenge (www.ewb.org.au/ewbchallenge) as the basis for first year team projects in most engineering faculties in the country. Every year, EWB nominates one of their partner organisations in a developing community, with a range of projects and themes addressing needs and work in that community, as the basis for the year's EWB Design Challenge. EWB develops and provides a suite of resources including on-line information about the community and the partner organisation's work. As of 2011, over 18,000 students at thirty-one universities in Australia and New Zealand had participated in the EWB Challenge. The nature of the projects provides the opportunity to expose students to the complexity and specificity of real-world projects where sustainability and usability are important factors and teamwork is required to manage the projects.

All of the universities involved have implemented this innovation differently and comparison of these different implementations afforded the opportunity to assemble[3] "a body of carefully gathered data that provides evidence of which approaches work for which students in which learning environments" (p.26) in pursuit of the desired outcomes.

The attribution problem

Curriculum innovation and change is more often driven by external factors such as changes in the field or informal feedback from students and staff rather than systematic data collection[3,6]. A preliminary study of the EWB Challenge at The University of Queensland[7] indicated that at the very least students felt that they had been motivated by the experience, learned how to perform in teams and appreciated the wider role of engineering in society as a result.

However, an unanswered question remained as to whether this or any course innovation is responsible for the outcomes attributed to it. Students are doing much more than just their project work during the semester and there might be many possible causes for any given outcome. In addition there is commonly a range of responses in the student body to any innovation. This creates a problem for staff who want to build on the perceived benefits of an innovation such as the EWB Challenge, since it is not clear what outcomes can be attributed to what mechanisms and under what circumstances. For instance, the experiential learning attributed to teamwork on real life projects such as this can be more assumed than proven. In this project we were interested to identify which aspects of context had an influence on the way students went about learning and how those choices affected learning outcomes.

Methodology

Data about how the intervention was being implemented was collected at 13 universities in Australia and New Zealand over Semesters 1 and 2 of 2011. We began data collection with a series of program logic analyses[8] with each course controller and, where available, their teaching team. The program logic analysis (Table 1) is a method for uncovering the underlying logic of what is involved in a given intervention and how it is understood to produce the desired outputs, outcomes and impacts. Our method is based on the standard Wisconsin model[9, 10] and allowed us to gain an understanding of the variety of approaches and intended outcomes across the 13 sites. It also helped identify where there was divergent thinking within a team and places where unintended consequences might be expected. At this stage we also identified useful sources of data and time lines and processes for the data collection.

Table 1 Program Logic Matrix

Program Logic

GOAL:

OBJECTIVES:

INPUTS	ACTIVITIES	OUTPUTS	OUTCOMES	IMPACTS
What we invest in the program	What we do in the program	What our activities produce	Short to medium term behavioural change	Ripple effects

Data collection started in semester 1, 2011 and included document analysis, observation of classes, focus groups and interviews and a student exit survey. The analytic framework used for dealing with this vast body of data was drawn from the Realist Evaluation work of Pawson and Tilley[11]. This approach to evaluation is based on the premise that it is not enough to ask whether an intervention works or not. What works in one place may not work equally well under different circumstances, and various factors will account for the different outcomes. In order to be able to elicit the kind of understanding that will allow us to generalise our findings we must identify what factors in the context make a difference, and the range of possible responses to the intervention. Pawson and Tilley express this as a formula:

$$C + M = O,$$

where C stands for “contexts” (understood as the sociocultural conditions that set limits on the efficacy of the intervention), M stands for “mechanisms” (the decisions to change that are triggered by the intervention) and O stands for “outcomes” (which may be unintended as well as intended). Data analysis was qualitative rather than quantitative, seeking to identify the contexts and mechanisms with most significant impact rather than those that occurred most frequently. Data was managed in the software program NVivo10 and analysed using constant comparative method.

Broad level findings

It is impossible in a paper of this length to do justice to all of the findings of a very large project. Instead we will explain briefly the major clusters of context and mechanism factors and pick out one or two to discuss in more detail.

Our analysis was a “grounded” one in that we searched the data for recurrent patterns of contextual influence and mechanism leading to observed outcomes. The analysis of Contexts, for instance, concentrates, on how best to understand the factors affecting outcomes rather than working with pre-conceived notions of what may be significant in the context (such as, for instance, “online”).

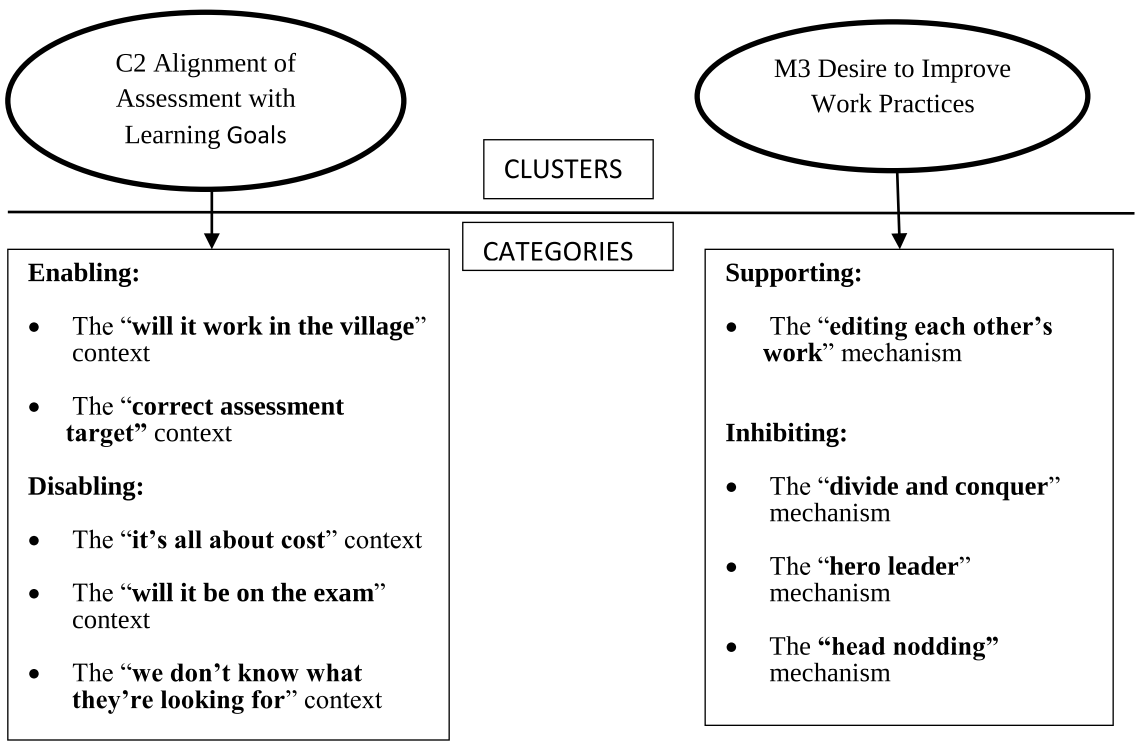

Figure 1: examples of cluster and category level factors

We drew on Sochacka’s[12] two-level analytic model (Figure 1 is an excerpt from the whole analysis) in which coded data with similar underlying features were grouped together first into categories which had either positive or negative effects. These categories embodied the range of phenomena present in our data and were labeled with *in vivo* codes for clarity and immediacy. At a higher level, categories were grouped again into abstract analytic clusters which attempt to capture the general principle at work. At this level we would expect the cluster factors to be generalisable across different situations and so it is no surprise to find they embody some very general pedagogic principles.

Contexts

Contexts are the sociocultural conditions that determine what outcomes can be achieved and the relevant contexts were not only those which appeared frequently in the data but also those where we had evidence of significant impact. We found that there were five relevant contextual factors: stakeholder commitment, alignment of assessment with learning goals, a focus on the conditions of use of the design, teachers embodying course goals in their practice, and the fact of the projects being "real world" (Table 2).

Table 2: Contexts of significance at the cluster level

Cluster	**Description**
C1 Commitment of Stakeholders to Learning Goals	This cluster is concerned with the broadest institutional aspects of implementing the projects including factors affecting status, purpose and perceptions of the course within its program context.
C2 Alignment of Assessment with Learning Goals	This cluster includes the degree to which assessment activities and criteria actually address the desired outcomes and the clarity with which assessment requirements are communicated and understood.
C3 Focus on Conditions of Use of Design	The degree to which teachers and course designs concentrate on either technical concerns or end-user concerns, creates a set of socio-cultural conditions that affect what tasks will be pursued and therefore what attributes will be developed.
C4 Teachers Operationalise Course Aims	This cluster includes a range of observed approaches to the task of leading students through the learning to attain overall objectives. The kinds of mastery demonstrated by teachers were likely to influence how and what students set about learning.
C5 Use of Real World Projects	Understandings of the projects as work in the real world for real clients has an effect on both student and teacher approaches to the task and how well the objectives are realised.

The context we have chosen to illustrate our analysis of context factors is one of the categories from C2, which could be understood as equivalent to the well-known principle of constructive alignment[13,]. We labeled this the "correct assessment target" context (Figure 1). While many of the staff we interviewed identified non-technical skills such as communication and the need for sustainable design as desirable learning *outcomes*, in practice assessment most commonly centred on *outputs* such as written reports and oral presentations. Where the focus was on the outputs, conditions were created that prompted students to adopt the "divide and conquer" mechanism which we will describe in the next section.

There were two approaches to assessment design which provided better learning outcomes; one through the use of portfolio assessment and one through a Demo Day where students had to demonstrate and justify their models/prototypes in public, rather than just talk about them in class. The course using portfolio assessment listed learning objectives that looked very similar to everyone else's, but instead of expecting targets such as communication to be embedded in a written report, students were required to keep detailed records of their work over the semester and to use those records and their final report to argue for the extent to which they achieved the outcomes.(Figure 2).

Details

Formal assessment is by submission of a portfolio which contains all of the individual student's work for the term. A portfolio is used to allow individuals to choose the method that best suits them to demonstrate how the learning objectives have been met and to what level. The portfolio must include all pieces of work produced which the individual claims can demonstrate how the individual has met the learning objectives of the course. Clearly individuals will want to refer to team submissions. These should be referred to rather than full copies being included in the portfolio providing copies are in the possession of the lecturers at the time of assessment of the portfolio.

The portfolio will be followed up with a compulsory individual Viva Voce (oral interview) that will be used to confirm and enhance the material presented in the portfolio. This viva voce will occur in the exam period and the time will be confirmed in week 12.

The **team project submissions** will be used as (formative) feedback only to the team. The formative feedback will not contribute to an individual's final result. However, the projects must be handed in during the term and considered acceptable by the supervisor for the team members to be eligible to be graded at the end of the term. Submissions not considered to have reached the minimum required standard will be given the chance to be resubmitted. Project requirements completed satisfactorily and handed in after the due date may be accepted but the final grade will be affected.

Figure 2: Example of portfolio assessment guidelines.

Although no marks were received for the project work in this course, students were enthusiastic about this mode of assessment and felt it was relevant to their future professional lives.

The course using the Demo Day as a major part of their assessment, allowed their students to choose one of four different projects, only one of which was the EWB Challenge. However, all four were constructed to allow for an emphasis on "engineering in practice" and required students to consider how contexts of use and user needs affect design. The students had to build a model/prototype of their design and demonstrate it in a public place on campus where they could be asked questions by invited industry professionals, staff and senior students and interested passers-by. Class discussions within student teams were more than usually collaborative and inclined to try a range of innovative solutions. However, the outcomes were highly dependent on how the context of the problem was articulated and how well the conditions of the Demo Day could be compared to conditions of actual use[15]. So the groups designing bridges for emergency deployment were told that their task was to sell their ideas to a client and the resultant designs were very often incapable of being scaled up for real-world use. In another case, designs for water purification that would have worked in the field were rejected by students because they didn't have enough time to show effectiveness on Demo Day. Such issues were identified by staff and rectified in subsequent course offerings. Overall the Demo Day assessment set conditions for learning that helped support the development of outcomes such as communication skills and teamwork that are so hard to see demonstrated in a report.

Mechanisms

The mechanisms are the factors influencing the choices people make in response to the intervention. At the highest level, these choices were found to be influenced by considerations of outcomes that were important to participants, their desire to change their work practices, and awareness of broader engineering practice. For this research, outcomes considerations were separated into sustainability outcomes and all others since sustainability was identified by course controllers as a desired learning outcome and the literature shows that educators struggle with the idea of educating for sustainability[14]. Table 3 shows the significant mechanism clusters that were identified.

Table 3: Mechanisms of significance at the cluster level

Cluster	Description
M1 Outcomes motivated considerations	This cluster of mechanisms includes the outcomes-focused consideration that changed the balance of choices open to participants. Where teaching staff and students could identify tangible and relevant benefits, outcomes tended to improve.
M2 Sustainability motivated considerations	This cluster includes factors related to sustainability that changed the choices people made. This cluster indicates that there is some progress yet to be made with respect to this outcome.
M3 Desire to Improve Work Practices	This cluster includes decisions about how work was to be carried out. The relevant contrast here is between process as part of the learning and production of an output.
M4 Awareness of Broader Engineering Practices	This cluster relates to decisions and choices made in the light of participants' understandings of how the projects and associated learning fitted into actual engineering practice.

A mechanism that was very widespread in our data was one we called the "divide and conquer" mechanism. This is the familiar process where students look at the assessment requirements as a report that has to contain certain sections, decide which of them has the best skills for the various tasks involved and divide the work up accordingly. We are often told that this is standard practice in industry where the object of group work is to produce a product of some kind, but we question its effectiveness for fostering learning outcomes.

In one university, staff actually facilitated "divide and conquer" by advising students how to divide the work between them. They were then surprised to find that when the teams came to give oral presentations of their designs, members of the team could answer questions on their own sections of the work only and had ignored what other students were doing. The most immediate result of "divide and conquer" is that students miss out on part of the learning of content and skills, but there were implications for the work process as well. Although nearly all of the course controllers said that they wanted their student to learn to work collaboratively, manage teams and communicate, the "divide and conquer" mechanism inhibited such learning. Team meetings were a matter of checking that everyone was making progress on their part of the report rather than an exchange of ideas. Communication was reduced in many cases to memos and minutes, enthusiasm was hard to maintain and complaints about team members not living up to their responsibilities created problems for academic staff.

The context that was most significant for triggering and supporting the "divide and conquer" mechanism was, in our opinion, a matter of not setting the correct assessment target, that is being more concerned with the output than the outcome. However, this was not the only contextual factor in play and we could also point to issues of insufficient institutional resourcing (C1), and instances where the purpose of the design task was lost in a focus on the acquisition of technical skills, as also having an influence. A particular instance from our data is illustrated in Table 4.

Table 4: The logic of an unintended outcome

Context	+	**Mechanism**	=	**Outcome**
Some lack of clarity in expectations, the **"don't know what they're looking for"** context, which tutors try to clarify by either telling them how to approach teamwork through capitalising on existing capacities ("**feeding information**") or specifying a variety of different criteria according to their own preferences and understanding **("idiosyncratic processes").**		Students use the **"divide and conquer"** mechanism as their only group process.		When doing their oral presentations it was found that many members of most groups could only answer questions about the small section of the report they had actually worked on. They could not discuss and therefore probably had not achieved the learning outcomes in the other aspects of the project.

Moreover, contexts and mechanism interact with each other, so that even in cases where the assessment was focussed on the report and "divide and conquer" was the chosen mechanism, the outcomes were improved by the influence of other contexts and mechanisms. For instance, amongst the M1 cluster, Outcomes focussed mechanisms, there was a strong trend for students to respond to courses on the basis of their understanding that engineering was a profession that allowed them to make the world a better place. They also wanted to take on responsibility for their work. Those two mechanisms helped to mitigate the worst defects of the "divide and conquer" response.

Implications

We began by noting calls, which have been current for some decades, for engineering education to change in ways that could be described as paying more attention to the conditions in which engineers work (in multidisciplinary projects requiring sophisticated communication) and the impact their decisions can have on the world. Overall we conclude that use of the EWB Challenge projects provides good opportunities for pursuing the desired changes to learning outcomes for engineering students, although other kinds of projects could be equally successful as long as some basic principles are followed. Achieving best outcomes, regardless of the type of project chosen, is more likely where there is:

- Commitment to and clear and detailed communication of rationale for the intervention and its methods,

- Well-aligned course and assessment design that does not rely on content alone to structure learning outcomes,
- Attention to outcomes rather than outputs, and
- Coherence in teaching approaches across the teaching team and in line with stated objectives.

In other words, the change we need is not the inclusion of new content or a focus on non-technical skills, but rather the embodiment of the kind of engineer society is demanding in ourselves as teachers and in our courses.

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