Best practice or business as usual? Whose interests are served by the engineering science paradigm?

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Abstract: *From the excitement of common1st year engineering courses and other design-build/project-based learning units, there is a massive drop in student engagement with the engineering curriculum as the students enter the 2nd/3rd year barrier courses, and a concomitant high rate of attrition or lack of progression. The early excitement is often never rediscovered, as by the time the students start their 4th year they have lost some of their enthusiasm, and much of their ability to solve ill-structured problems. Although there are several examples of innovative engineering programs in Australian universities, the majority of engineering faculties follow a deeply traditional curriculum model that has not changed for decades, despite major shifts in technology and industry in the outside world. This paper presents perspectives from industry, academics and students on the current engineering curriculum across four Australian universities and suggests a change model that could provide authentic learning experiences for students by developing a formalised nexus between industry and academia.*

Introduction

The need for a more integrated and student-centred engineering curriculum has been identified both nationally and internationally over a number of decades and in a considerable number of reports (e.g. ASEE 2009; King, 2008; Royal Academy of Engineering, 2006; Sheppard, Macatanga, Colby & Sullivan 2009;). In particular, there have been repeated calls for engineering curricula that prepare students for the future rather than for the past (in addition to the above-mentioned reports, see also Goldberg 2009; Grasso & Martinelli 2007; Lucena 2003; Wulf & Fisher 2002).

This need can be framed as a series of gaps or inadequacies in the prevailing curriculum:

- the gap between technical and professional competencies (Engineers Australia stage 1 competencies) and where, when, whether and how they are taught;
- a lack of engineering practice in the engineering program as it is taught/learned in the majority of Australian universities;
- a disconnect between the theory and practice in the degree: students cannot necessarily see the links or contextualise the theoretical knowledge that they are taught;
- a lack of ability by students to solve ill-structured/authentic problems.

The overall problem can then be defined as being composed of:

- a lack of design as an integrating element throughout the years of the degree;
- a lack of integration of theory and practice, which then links to:

- a lack of integration of technical and professional competencies in the curriculum;
- for the most part, traditional teaching delivery (where little has changed since the 1960s).

This is still the norm in Australian engineering faculties, despite years of research into curriculum renewal, significant advances in the learning sciences and despite a few excellent programs that successfully integrate theory and practice with problem-based and project based learning. Therefore, it is obvious that the predominant model of the Australian engineering curriculum, with its emphasis on theory over practice, and on science over design, needs to change. What is perhaps less obvious is why there has been so little response to this situation, notwithstanding the national and international recognition of quite momentous changes in industry, technology and global communications. The reasons are complex, but the resistance to change seems to coalesce around the following areas:

- Institutional: promotion/progression incentives focused on research, with concomitant disincentives to focus on teaching (Goldberg 2009; Strong & Stiver 2005)
- Pedagogical: belief in the knowledge transmission approach to teaching as being most appropriate (Samuelowicz & Bain 2001)
- Epistemological: belief that knowledge is an independent entity rather than co-constructed (dualistic rather than relativistic) (Schommer 1994)
- Epistemological: belief in the engineering science paradigm as representing what engineering is in the real world (Dym et al. 2005; Goldberg 2009; Pawley 2009)

The King report (2008) identified several of these issues and made a range of recommendations, some of which formed the basis of the ALTC project *Design based curriculum reform in engineering education,* in particular the following:

- *Define curricula more strongly around engineering problem solving, engineering application and practice, and develop the themes of design, model-and network-centric engineering, the engineering life-cycle, complex systems, project management, global workflow, and multidisciplinarity* (King 2008: 107)

This paper presents selected findings around some of the research questions of the project. These questions include: how to design engineering curricula in tune with the needs of industry in a fast-changing world; to what extent is there best practice in current engineering curricula in Australia; and how to deliver a curriculum that is based strongly around engineering problem-solving, engineering application, practice and design. The findings suggest the need for increased engagement with industry and the development of a design-centric engineering curriculum, exemplified by the CDIO Initiative (Crawley, 2001). Further, the paper seeks to explore some of the questions around why the status quo in engineering faculties has been maintained, despite national exhortations to respond to changes in the external environment.

The first set of findings is a continuation of the results from *Designing the future* (Goldsmith, Reidsema, Campbell, Hadgraft & Levy, 2009) which reported on the ALTC-funded forum *Designing Engineering Curricula* held at UNSW in 2009; here the stakeholder responses to the lack of engagement with industry in the current Australian engineering curriculum are presented. The second set of findings concerns the investigation into the current engineering curriculum in four major Australian universities, and presents results from a qualitative study that sought to discover the extent to which the teaching in engineering design reflects best practice, as well as what constrains its development. As the data analysis is ongoing, the results whilst incomplete are presented to ensure continuity of communication to the engineering education community. Some preliminary results have already been reported on in Goldsmith, Reidsema, Beck and Campbell (2010).

Methodology

Forum data: At the 2009 ALTC-funded Forum held at UNSW, the three key stakeholders in the Australian engineering curriculum – students, academics and industry representatives – participated in a series of workshops and plenary sessions over two days to identify the most important needs, trends and required graduate capabilities for the future (Goldsmith et al., 2009). The responses from the workshops were then inductively analysed using a thematic approach; two researchers independently identified emergent themes from the responses and then coded them under the most commonly occurring themes. For example, in a workshop activity on day 1 of the forum, all participants were asked: *What capabilities will employees, and specifically graduate engineers require if they are to effectively contribute to their organisations and communities into the future?* The themes that emerged were then grouped according to the graduate capabilities as identified by CDIO and Engineers Australia. A similar methodology was employed to analyse the responses to the workshops that followed this activity, and which sought to identify constraints and develop strategies to achieving better integration of technical and professional competencies in the engineering curriculum.

Curriculum snapshot data: The following methods have been employed in gathering data for this study:

Semi-structured interviews with academics: lecturers in engineering design and in engineering science subjects -thermodynamics, fluid mechanics, solid mechanics- (Lucena, 2003: 421) from each of the four partner institutions involved in the project were interviewed using a set of questions around the areas of: learning outcomes, learning activities and assessment, attitudes to graduate attributes, awareness of constructive alignment between learning outcomes and assessment, and attitudes to change. The interviews were audio recorded using a Smartpen and then transcribed verbatim and analysed thematically by the lead researcher. An assistant researcher is currently engaged in conducting an emergent theme analysis using NVivo, but no results from this are yet available.

Semi-structured interviews with students: Student focus groups (Stewart, Shamdasani & Rook, 2007), comprising students from the later stages of their engineering degree program from the four institutions were then interviewed; the group sizes were 4-6 students per group. The interview questions matched as closely as possible those that the lecturers were asked, and were also audio recorded using a Smartpen. The student focus group interviews are still being conducted and transcribed at the time of writing, so results are preliminary.

Mapping of individual units of study: the unit outline was obtained for each of the subjects above and mapped against the following categories: learning outcomes; learning activities related to learning outcomes; how the outcomes are taught; how the learning outcomes are assessed; how the learning outcomes match up to Engineers Australia (EA) graduate attributes (Engineers Australia, 2010). The mapping serves to triangulate the interview data as well as providing additional information about learning activities, teaching activities and assessments.

*Administration of the Approaches to Teaching Inventory (ATI) (*Trigwell & Prosser, 2004): after each semi-structured interview was conducted with the lecturer, the participant was asked to complete the ATI: a set of 16 questions around teaching intentions and strategies with a Likert scale range of responses, ranging from: “this item was rarely true for me in this subject” to “this item was almost always true for me in this subject”. The inventory attempts to capture the extent to which the teaching approach to a specific unit of study focuses on information transmission or on conceptual change (Kember & Kwan,1997; Samuelowicz & Bain, 2001; Trigwell & Prosser, 2004).

These three approaches triangulate the data to improve its validity as a piece of qualitative research.

Findings from the forum

The results of the analysis from the workshop activity identifying desirable graduate capabilities are listed in Table 1, and demonstrate that the professional competencies as identified by both CDIO (Crawley 2001) and EA (Engineers Australia 2010) are those most valued by the stakeholders (1, 2, 4), followed by competencies in engineering ability (3, 5, 6).

Table 1 workshop activity day 1: top 6 graduate capabilities

rank	***%***	***Graduate capabilities: CDIO/Engineers Australia***
1	26%	Personal skills & attitudes/professional attitudes
2	19%	Communication/Ability to communicate effectively

3	17%	Designing/proficiency in engineering design
4	14%	Teamwork/ability to function effectively as an individual & in multidisciplinary & multicultural teams
5	12%	systems thinking/ability to utilise a systems approach to complex problems & to design & operational performance
6	12%	conceiving & designing engineering systems/ Ability to utilise a systems approach to complex problems & to design & operational performance

(Adapted from Goldsmith et al., 2009, p. 4)

Interestingly, none of the top six categories included what CDIO refers to as *technical knowledge and reasoning* (Crawley, 2001), and what EA refers to as *knowledge base* (EA, 2010), indicating that the technical knowledge is assumed as a given, but that professional and engineering ability competencies are regarded as a critical gap in the workplace, as reported elsewhere (e.g. King, 2008).

In the next stage of the forum, workshop groups comprising members of all three stakeholders, considered constraints to achieving desirable outcomes in the engineering curricula in Australian universities, and devised strategies to overcome these constraints. One set of major constraints was around the lack of industry involvement in the engineering curriculum. The workshop groups considered this issue from the perspectives of the three stakeholders: how academia can engage with industry; how industry can engage in the university and how students can engage with industry and with academia as part of their engineering program. Table 2 shows several of the strategies that came out of the workshop activity.

Table 2: Workshop activity day 1: Strategies to overcome lack of engagement with industry in the current Australian engineering curriculum

Academics	**Industry**	**Students**
Academics return to industry to 're-skill'	Adjunct lecturers from industry	Students attend classes and "clinics" (Medicine model)
Engineering academics to have 5 years' work experience	Industry lecturers: latitude in teaching – negotiate a relevant package	Capstone design projects in collaboration with industry
Academic placements in industry 6 month terms	Construction projects on campus – contract provisions for site visits, student training	Career guidance at university for students so that they learn about the different roles of an engineer
No academic owns a course: it is part of a program	Consistent input & support from industry – licence condition for practising engineering firms	Co-op model: 2 internships 1st year – 10 weeks internship, repeated in 4th/5th year with same company
Mechanism to ensure promotion for *teaching only* academic appointments	Portal: small industry problems posted on website: academic proposal & student involvement leads to ongoing academic & industry involvement	1st year major design project integrated with other 1st year courses: industry-related assessment

It can be seen from this table that the overarching theme is that of an exchange of knowledge and experiences between universities and industry. What is particularly important to note, and was quite obvious over the duration of the forum, was the willingness of industry to engage with academics, with students and with the engineering curriculum. As with any such activity, some strategies may require more radical changes than others, in terms of curriculum infrastructure and university policies (such as hiring and promotion), but many are quite achievable and have been successfully implemented in several universities. This then begs the question: why is there not more widespread, sustainable engagement with industry in the current engineering curriculum? The next section of this paper goes some way to proposing reasons for this.

Findings from the investigation into the engineering curriculum

Interview responses from academics and mapped unit outlines: for the question: "What are the most important things that students learn in your unit?", the responses from four Engineering Science and four Engineering Design lecturers have been mapped against the Engineers Australia (EA) stage one competencies (Engineers Australia, 2010) which are the competencies at one level down from their broader Graduate Attributes. This has been done in order to convey the differences in types of competencies that are valued by the two cohorts. The stage one competencies are divided into three sub-headings: PE1 *knowledge base,* PE2 *engineering ability* and PE3 *professional attributes.* These responses were also checked against the mapped unit outline for each subject, to ensure accuracy.

Of the responses from the Engineering Design lecturers, there was one competency from PE1 (knowledge base). All the others were from PE2 (engineering ability): 13 in total - or PE3 (professional attributes): nine in total. In stark contrast, the responses from the core unit lecturers included one competency from PE3, one competency from PE2 and 15 from PE1.

Table 3: responses to "what are the most important things that students learn in your unit?"

Field	Knowledge base	Engineering ability	Professional attributes
Engineering design (4 subjects)	1	13	9
Engineering science (4 subjects)	15	1	1

The responses from Engineering Design lecturers included:

develop things to satisfy real people; understand that somebody has to make something that you design; that design is iterative; the engineering method; how hard it is to make things

The responses from Engineering Science lecturers included:

I guess the one technical thing we teach them is Bernoulli's equation; understand external forces and reactions and internal stresses and behaviours; the 1st law of thermodynamics; applying theory to other areas of engineering; they need to know how to read steam tables.

As can be seen, the engineering design responses centred around the importance of hands-on experience, of designing for real-world conditions and of considering the complexities of the design process. The engineering science responses were overwhelmingly focused on theoretical content

The responses to the question: "How do the students learn in your class?" are also revealing, with team collaborations and experiential learning being identified as learning experiences by Engineering Design lecturers. Engineering Science responses listed lectures, tutorials, self-study and observations of demonstrations/experiments. There was one mention of a site visit (to an old steamship).

The contrast here is again quite marked. Although there is a range of types of learning in the Engineering Design units of study, all the lecturers understood the importance of experiential learning and of working cooperatively. In the Engineering Science units of study, the model is that of the traditional lecture/tutorial structure. Even where there are demonstrations, in the majority of units the students are expected to observe passively, or at most note down the calculations.

When asked the question: "what is the best way of measuring student learning in your unit?" the responses included the following:

Table 4: lecturer responses to: what is the best way of measuring student learning in your unit?

Engineering Design	Engineering Science
concept maps; appropriate assignments; reflective journals; assessing their written work; continuous assessment; academic observation of student behaviour; the quality of the final product; exams; lab reports; projects.	*progress tests; e-learning exercise; final exam (measures individual learning); mid-session exam; (not assignments because students would copy from each other); (not labs) the final marks; during class (students asking questions); lab reports; producing the artefacts for testing.*

As is demonstrated by these responses, and by examining the unit outlines of all of the subjects which have been analysed for this study, the range and type of assessment tasks is far broader and more innovative in Engineering Design than in Engineering Science; the four engineering design units across the four institutions had a group project, whereas only one of the 12 Engineering Science units did. Moreover, the fact that one Engineering Science unit included a group project means that it is possible to include such a learning activity in a theory-oriented subject.

What becomes very clear is the value placed on individual learning as measured by quizzes, tests and final exams by almost all the engineering science academics. As is shown in the mapped unit outlines, the final exams are on average worth 70% of the final mark for the unit. This is despite compelling evidence that problem-based and project-based learning can be successfully integrated into content-laden units of study, both deepening understanding and developing conceptual change, without loss of technical knowledge (e.g. Brodeur, Young & Blair 2002; Gomes & Barton 2005; Hadgraft & Kolmos 2007). It also disregards educational research on assessment and backwash (Biggs, 2003; Tang, 1994), where students learn what they think they will be assessed on, so that if the assessment is perceived to require accurate reproduction of facts, students will then adopt a surface approach (Tang 1994, p. 152). This almost inevitably leads to the scenario where students focus their learning around the final exam, memorising facts and details. The implications for this are fairly clear, particularly in a design context, where practitioners are expected to be creative, divergent thinkers and solvers of ill-structured problems. The risk with an exam-focused teaching approach is thus that students will do little more than reproduce atomised pieces of information, and will then lack the ability to integrate knowledge into a coherent whole.

Semi-structured interviews with students: At the time of writing, the data collection and analysis is ongoing, but we have included some sample questions and responses to give an indication of student attitudes.

Table 5: selected student responses to interview questions

SSI questions	Student responses
"How did you learn?"	*-I think we were taught the theory with no application for it. Like we didn't actually understand what we were taught.* *- they just chuck all this theory at us and then like we're trying to work it out, but then when I actually see it it's like: Oh, that's what it all meant.*
"What were the best ways of measuring your learning?"	*-I remember going to TAFE and that was one of the most enjoyable experiences I had, because we got onto the machines.* *- exams – they're not realistic. You don't sit in your office at work and you have 3 hours to complete these questions and you can't reference a text book.*

"What is your understanding of graduate attributes?"	*-Because you need to know a real application for something, you can't just make something up in your head. You need these things to give like a real perspective.* *-And I think companies want people to think like that*

As can be seen, the student responses so far reflect much that has been identified as problematic or inadequate in the current engineering curriculum: an emphasis on content measured by exams; a disconnect between theory and practice; a lack of hands-on learning and an absence of authentic learning experiences. Moreover, the student responses reflected a strong desire to have authentic learning experiences, and showed an understanding of the need to apply knowledge to real situations.

Responses to the ATI: the 16 ATI statements attempt to capture the approach that a lecturer takes to a particular unit of study, and the extent to which it is information transmission/teacher focused or conceptual change/student focused, using a Likert scale 1-5. There was a wide spread of responses from both cohorts, with only some responses showing a clustering around either end of the scale. For example, the responses to the statement: "*I feel a lot of teaching time in this subject should be used to question students' ideas*" showed a cluster of Engineering Science responses at the lower end of the scale, and Engineering Design responses at the upper end, indicating that the Engineering Science approach was less comfortable with engaging in discussions around conceptual change. However, the responses to the statement: "*In this subject, I only provide the students with the information they will need to pass the formal assessments"* showed an identical spread between the two cohorts, with all responses clustering at the lower end of the scale ("rarely true for me in this subject"). At the time of writing, the ATI responses have been included as part of the emergent theme analysis (ongoing) using NVivo, which may reveal more consistent patterning.

This study could have the following limitations: as it is based in qualitative research, the findings may not be generalisable across all Australian universities. Furthermore, as the analysis is ongoing at the time of writing, other findings may emerge that challenge the current results. In particular, the student focus group data is preliminary, so could well not be representative of the majority of engineering students.

Discussion

From the two sets of findings, the following points can be made: firstly, there is a broad consensus that professional competencies are seen to be highly desirable by all three stakeholders, and that there is a need for graduate engineers with the ability to design as well as to communicate and solve real-world problems. Secondly, there is an expressed willingness by industry representatives to engage with the engineering curriculum to provide opportunities for authentic learning experiences for students, as well as to facilitate an exchange of experiences between academia and industry. Thirdly, there is a major disjunct between the teaching and learning of Engineering Science and of Engineering Design across the four institutions, with the former being firmly anchored in a traditional, content-laden, theory-oriented model, while the latter attempts to coordinate the technical and professional competencies and to provide students with opportunities to engage in experiential learning. Moreover, the preliminary findings from the student focus groups demonstrate clearly that students value authentic, deep learning experiences, and that they perceive the engineering science paradigm as inadequate for graduating them as engineers.

To date, the great majority of Engineering Science lecturers cannot see another way of teaching their unit (in response to the question: "if you had all the time and resources at your disposal, how would you design this unit: what changes would you make?"), except to increase the number and size of laboratories, with a concomitant increase in numbers of tutors. This lack of willingness to engage in innovative education practices will militate strongly against forms of curriculum renewal such as an integrated curriculum, given that there needs to be whole-of-faculty support for implementing these changes (Froyd & Ohland 2005; Wormley 2004).

This then leads to the observation that the current engineering curriculum as predominantly practised in Australian universities serves the interests neither of the students nor of industry. Whose interests, then, does it serve? One conclusion to be drawn is that it maintains the status quo for the majority of research-focused engineering academics who have little industry or educational experience; it could further be inferred that they not penalised for this, or indeed are rewarded by promotion and progression. Whether or not this is the case, the situation remains that change must occur, if the needs of two of the three stakeholders (industry and engineering students) are to be met, and in order for this to eventuate there needs to be a robust and sustainable change model that can be put in place.

The final phase of the ALTC project *Design based curriculum reform in engineering education* is working on developing just such a change model, which will foster a research-industry-learning nexus. Due to word limit constraints, only the briefest of summaries can be provided here:

- Many faculties and schools of engineering lack research income
- The best way to gain traction for research income is through linkage with industry
- BUT academics lack the time and experience to develop/explore these linkages

Solution: broad channel engagement and exposure from industry to academia and vice versa, via 3rd and 4th year design projects which will develop the research-teaching nexus.

What it needs:

- A sustainable and integrated framework
- A structure that is more than relationship-driven: a designated unit that coordinates and manages the information and exchange from universities to industries, and from industries to universities.

This change model will be further developed and presented to a regional forum in late 2010, where it can be evaluated by the stakeholders (academia, industry and students), and where it is hoped a workable framework for the model can be devised. It is intended that a workshop at the AaeE 2010 conference will then present this framework for discussion and review by workshop participants.

This project team will report on further findings and developments as they arise.

ACKNOWLEDGEMENTS

Many thanks to all the lecturers and students who agreed to participate in the interviews.

Support for this study has been provided by the Australian Learning & Teaching Council Ltd, an initiative of the Australian Government Department of Education, Employment and Workplace Relations. The views expressed in this paper do not necessarily reflect the views of the ALTC.

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