Design based curriculum reform within engineering education

Final Report 2011

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Funding for the production of this report has been provided by the Australian Government Office for Learning and Teaching. The views expressed in this report do not necessarily reflect the views of the Australian Government Office for Learning and Teaching.

Acknowledgments

Support for the production of this report has been provided by the Australian Government Office for Learning and Teaching. The views expressed in this report do not necessarily reflect the views of the Australian Government Office for Learning and Teaching.

2012

ISBN [978 1 921916 85 4] PDF
ISBN [978 1 921916 83 0] Print

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Executive summary

The primary objective of this project has been to investigate the capability of the current Australian Engineering Curriculum to implement design-based curricula that might meet student, academic and employer needs through delivering an integrated and balanced set of technical and professional competencies. The overall aims of designing engineering curriculum to deliver a balance of theory and practice competencies underpin the reports' recommendations for specific models for change and the strategies necessary to achieve this change.

The reasons for change within the Australian Engineering Education sector are well documented in the 2008 Review of Engineering Education and through the Learning and Teaching Academic Standards Project in 2010. Both of these are well aligned to an increasing number of international initiatives and reports on the need to renew engineering curriculum to meet the needs of the 21st century. Without exception, the central conclusion is that there is a disjunction between theory taught at university and engineering practice. This has resulted from historical institutional and cultural practices of preparing undergraduates for research rather than for industry. These historical trends have led to the current culture reinforcing existing practices where research is increasingly seen as the real purpose of academics exemplified by the dominant engineering science paradigm.

This project began by identifying the extent to which the engineering curriculum as practised in the four participating universities aligns to a design-centric syllabus such as CDIO. From the collection of data beginning with an Industry-Academic Forum in April 2009, followed by student and staff surveys and interviews across the four partner universities three main recommendations emerged in the areas of: (1.) Advocacy, (2.) Professionalization of TL, and (3.) Engagement with Industry which could address the core issue uncovered by the research project: that the prevailing epistemological beliefs and pedagogical practices of engineering academics are the critical barriers to change.

1.0 Introduction

Aims

The key aims of this project were to investigate the current state of the curriculum with respect to the teaching of Engineering Design at four universities (3 Go8's and 1 ATN), determine the extent to which the mix of engineering science fundamentals and design teaching reflected best practice, and arrive at a preliminary understanding of what constrains the development of best practice as defined by an appropriate balance of technical and professional competencies as defined by Engineers Australia's Stage 1 Graduate Competencies. Specifically the aims were to:

- Conduct a detailed comparative study of the engineering curricula at the four partner institutions against EA graduate competencies and against international best practice as represented by the CDIO pedagogical framework,
- Create a community of practice based on the four partner institutions and to expand this through a number of regional forums involving industry and academia,
- Inform the design and development of an innovative Australian engineering curriculum that has the integrated development of technical and professional competencies at its core.
- Recommend implementation strategies for the new curriculum, within identified current constraints
- Disseminate the findings widely through workshops, seminars, publications and collaboration with aligned projects.

Background

The ALTC project PP8-9191 "Design based curriculum reform within engineering education" builds on the outcomes and recommendation of a previous ALTC project report entitled "Engineers for the Future: addressing the supply and quality of Australian engineering graduates for the 21st century" (King, 2008). This project and its subsequent report built on the 1996 Review of Engineering Education (Engineers Australia Report). There were three recommendations from the King Report that this project sought to address:

- Recommendation 3: implement best-practice engineering education
    - Engineering schools must <u>develop best-practice engineering education</u>, promote student learning and deliver intended graduate outcomes. Curriculum will be based on sound pedagogy, embrace concepts of inclusivity and be adaptable to new technologies and inter-disciplinary areas.

- Recommendation 4: improve resources for engineering education
    - <u>Enhance staff and material resources</u> to enable delivery of engineering education that is demonstrably aligned with Australia's needs and compliant with international standards.

- Recommendation 5: engage with industry
    - Engineering educators and industry practitioners must engage more intensively to strengthen the authenticity of engineering students' education.

This report reveals that whilst progress has been made in addressing the concerns raised in a 1995-96 review of the national engineering education system (IEA 1996 in King 2008), there are areas that have not progressed as expected. The areas relevant to this project are:

- High levels of student attrition
- Lower incentives within the system for improving teaching than for developing research
- Effect of research appointments over teaching appointments and barriers to promotion
- Concerns that the balance of subjects within current engineering curricula are not adequately matched to graduating students and industry's current and future needs

Developing Best Practice Engineering

Engineering Design can be defined as:

"….a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients objectives or users' needs while satisfying a specified set of constraints…"

The design process is itself a complex cognitive process" (2005: 104). As such, learning engineering design requires deep and authentic learning experiences, yet these are difficult to locate in the current engineering science curriculum. Part of this lack can be traced back to the hiring and promotions policies of Australian Engineering faculty, but this issue is neither local nor recent: "The prominence of hiring faculty without experience in engineering practice does not lend itself to progressive design education. The doctoral graduates from leading engineering schools have focused on research publications and are sought after by academic departments. The reward system encourages them to follow the same path, with the result being that several generations of faculty members "…have never left the campus and they neither understand nor appreciate the role of the technical innovator in society‟ (Brown 1985, in Strong & Stiver 2005: 3). This comment was made about the US context; Strong and Stiver also make the point (from a Canadian perspective) that while it is necessary to include open-ended design problems in an engineering curriculum, such problems can create difficulties for academic staff who lack industry experience (2005: 3) .

Sheppard states, "The best learning happens as experts model performance in such a way that learners can imitate expert performance" (2009: 185). The concept of a design-oriented, integrated curriculum is based on the premise that Design competencies lie at the heart of effective engineering practice and that real-world problems require the support of theory rather than theory requiring the search for problem applications. It stands to reason that the formation of these competencies can only occur within a curriculum whose context is representative of a community of experienced practitioners who can perform or model the ways of understanding, seeing and engaging with complex socio-technical issues that we expect our students to learn. In order to achieve this we would also require staff who are cognisant and actively developing and researching best practice educational and learning methods. It would thus appear that we have an obvious problem.

The King report (2008) called for significant curriculum renewal in engineering education in Australia, and made specific reference to examples of best practice in engineering education that should be implemented:

Examples of best practice in Engineering Education, as outlined in the King Report (King 2008: 107) include:

- A more adequate understanding students' learning styles, practices and desires
- Systematic and holistic educational design practices with learning experiences and assessment strategies that focus on delivery of designated graduate outcomes
- Increasing graduate satisfaction with educational experiences and transitions to employment
- Increasing employer satisfaction with engineering graduates
- Increasing recognition of pedagogically sound, innovative and inclusive curricula
- Defining curricula more strongly around engineering problem solving, engineering application and practice, and developing the themes of design, model-and network-centric engineering, the engineering life-cycle, complex systems, project management, global workflow, and multidisciplinarity

It is the last point in this list of best practice in engineering education that the current report has aimed to explore with the underpinning rationale that strengthening engineering design abilities require a balanced curriculum with both theory and application.

2.0 Project Outcomes and Impacts

Approach and methodology

The project was carried out by a multi-institutional team based at The University of New South Wales. The project team consisted of: Associate Professor Carl Reidsema, team leader and Chief Investigator (CI) 1 – UNSW; Ms Rosalie Goldsmith, lead researcher – UNSW; Associate Professor Roger Hadgraft (CI 2) – The University of Melbourne; Associate Professor Duncan Campbell (CI 3) – QUT; Ms Hilary Beck, researcher – QUT; Associate Professor David Levy (CI 4) – The University of Sydney; Mr Al Popp, researcher, The University of Sydney. Dr Sue Wright from The University of Melbourne also provided valuable assistance.

Methodology

Summary of methodology

STAGE 1	
1	Literature review
2	Refinement of research questions
3	Regional Forum 1 UNSW
4	Analysis of Forum 1 data
STAGE 2	
1	Unit outline mapping and analysis
2	Face to face structured interviews with engineering design & engineering science academics
3	Administering the Approaches to Teaching Inventory (ATI)
STAGE 3	
1	Transcription & analysis of interviews with academics
2	Student focus group interviews
3	Regional Forum 2 The University of Queensland
4	Regional Forum 3 (workshop) AaeE annual conference Sydney, 2010

Research questions:

1. What is the current engineering curriculum as exemplified by the four participating universities?
2. To what extent do these curricula demonstrate best practice (using CDIO as a benchmark)?
3. Where are the gaps in the current curricula?
4. What are the barriers to adopting best practice?

The work required to address these questions was distributed amongst the 4 partner institutions as follows:

1. Co-investigator Duncan Campbell and RA Hilary Beck were assigned to work on the development of a software mapping tool to be used to map CDIO, Engineers Australia and the Engineering Faculty graduate attributes at the 4 participating institutions;
2. Co-investigator David Levy and RA Al Popp were assigned to the task of mapping and comparison of UNSW, UMelb, QUT and USyd, Engineering Faculty graduate Attributes, curriculum structures, learning styles, outcomes and mechanisms to the CDIO Syllabus
    a. NOTE: Both QUT and USyd were jointly assigned to develop an active and strong presence through involvement with the CDIO organisation
3. Co-investigator Roger Hadgraft was assigned the task of developing a web-based shared repository of best practice resources
4. Chief Investigator Carl Reidsema and RA Rosalie Goldsmith were assigned the primary research tasks and managing the project. These tasks consisted of the following:
    a. Collating the mapping results from the co-investigators of the engineering curriculum at the four universities
    b. Development of the semi-structured interview questions
    c. Organisation and conducting face to face structured interviews
    d. Administration of the ATI
    e. Organising and conducting student focus group interviews
    f. Organising and running three industry/academic forums
    g. Analysis and interpretation of the interview transcripts

The results of these activities aligned to the research questions allowed us to build a reasonably clear picture of the extent to which the prevailing engineering curriculum at the four institutions either did or did not map to the CDIO syllabus as an exemplar of design-centric best practice, assisted in identifying where gaps in achieving this best practice where and what critical barriers are needed to be addressed to achieve best practice. We then investigated the reasons for the gaps in current curricula and the barriers to adopting curriculum renewal. The findings from the latter investigation form part of the outcomes of the project.

Outcomes

The current engineering curriculum at the four participating universities, as mapped by unit outline analyses against well-established principles for constructive alignment against both the CDIO and Engineers Australia (EA) Stage 1 Competencies revealed that best practice was evident in all four institutions, but only in isolated pockets (See Appendix). The Engineering Design units generally contained elements of project-based learning, team work, group work, design-build projects and peer review, but the majority of the units examined were dominated by the engineering science paradigm, with heavy emphasis on technical content, individual learning and exam-oriented assessment. The engineering science units of study: fluid dynamics, mechanics of solids and thermodynamics (Lucena 2003: 421) focused very much on the development of knowledge base (EA PE1), with some emphasis on engineering ability (EA PE2), and very little (if any) development of professional and personal competencies (EA PE3). We then conducted an investigation to determine what were the reasons behind the barriers to curriculum renewal, and developed a robust data collection in order to provide evidence for our findings.

When we considered the barriers to adopting best practice or curriculum renewal, the following areas of resistance were identified:

- Epistemological - Positivist paradigm: knowledge as an independent entity; lecturer as holder of knowledge; content all-important; Engineering science paradigm represents engineering in the real world
- Pedagogical - Lecturer as expert – students as recipients; Knowledge transmitted; Learning outcomes content-focused; Individual learning valued; Group/collaborative learning viewed with suspicion; Exams best way to measure individual learning; Assignments not a true measure of learning, as there can be collaboration; Plagiarism feared (part of collaboration)
- Institutional - Promotion/progression incentives focused on research; Academic staff are selected/employed based on their research; Lack of focus on teaching; Lack of rewards for good teaching; Lack of emphasis on pedagogical knowledge
- Academic Characteristics - Research profile; Lack of pedagogical knowledge

Critical success factors

1. High interest from industry, academics and students in the project
2. The development of collaborative networks with ALTC Discipline Scholars
3. The development of collaboration with the ALTC Discipline Support Scheme combining established ALTC project leaders and Associate Deans TL
4. Strong involvement with CDIO International
5. Forums with Industry and development of future resulting contacts
6. Decision to run the core research from CI-1 institution with researcher
7. Ability to identify discipline gatekeepers at the participating institutions to facilitate cooperation in data gathering.

Things that worked against us:

1. Difficulty in finding a discipline qualified researcher
2. Lack of funding for appropriate level of researcher (data analysis)
3. Relocation of CI-1 to The University of Queensland
4. Scope of project too ambitious
5. Lack of a more formal Steering Group and Project Management framework

Outcomes

Table 2 summarizes the outcomes of the project and details of how these outcomes can be accessed.

Table 2: Summary of Project Outcomes

Title	Date	Access or Contact Details
Graduate Attribute Mapping Tool (QUT)	Dec 2009	Contact Duncan Campbell da.campbell@qut.edu.au
Unified Code Mapping Tool (USyd)	Dec 2009	http://aaee.com.au/conferences/AAEE2009/PDF/AUTHOR/AE090026.PDF
The Project Handbook (UMelb)	Dec 2009	http://project-handbook.pbworks.com
REFEREED PUBLICATIONS		
Goldsmith, R., Reidsema, C., Beck, H., (2010) Perspectives on teaching & learning in Engineering Design across 4 universities, ConnectED 2010 2nd International Conference on Design Education 28th June – 1 July 2010, The University of New South Wales, Sydney, Australia		
Reidsema, C., Goldsmith, R., Mort, P. (2010) Enabling the Reflective Practitioner through Engineering Design Courses, ConnectED 2010 International Conference on Design		
Goldsmith, R. Reidsema C. (2010) Best practice or business as usual? Whose interests are served by the engineering science paradigm? AAEE Conference, Sydney, 2010		
Goldsmith, R., Reidsema, C., Campbell, D., Hadgraft, R., Levy, D. (2011) Designing the Future, Australasian Journal of Engineering Education, Vol. 17, No. 1		
Reidsema, C., Hadgraft, R., Cameron, I, King, R. (2011)Change Strategies for Educational Transformation, AAEE Conference, Fremantle, 2011		
Cameron, I., Reidsema, C., Hadgraft, R., Australian engineering academe: a snapshot of demographics and attitudes, AAEE Conference, Fremantle, 2011		

3.0 Dissemination

Workshops and Publications

Table 3 details workshops and presentations given on the progressive results of this project.

Table 3: Dissemination (2008-2010)

Date	Event	Purpose of the event	Number attended
Nov 08	Workshop	Teaching Styles for the AAEE 2008 conference (Yeppoon)	30
Dec 08	Meeting of ADTL's	Curriculum specification and support systems for engineering education that address revised qualification standards	35
Apr 09	Forum	Regional forum 1 @ UNSW in Sydney	100
May 09	Workshop	EA ADTL Accreditation workshop at UTS	45
June 09	Conference	CDIO conference in Singapore	300
June 09	Workshop	ALTC-funded workshop on the B Factor	54
Dec 09	Workshop	CDIO Workshop conducted at AAEE 09	36
Dec 09		ETL Forum, Adelaide (DSS via AaeE)	39
June 10	Forum 3	ALTC Forum: Strategies for Change: Brisbane	54
June 10	Conference	2010 ConnectEd International Design Education conference (paper presentations)	240
June 10	Conference	Presentation of conference papers at CDIO conference in Montreal June 2010	140

4.0 Linkages

Institutions

National collaboration
There have been no significant institutional collaborations outside of the four participating universities.

International collaboration
CDIO; Olin College; Purdue University; University of Illinois

Projects

The outcomes of this project have been utilized in a nationwide survey that was instigated as part of several Australian Learning & Teaching Council (ALTC) projects addressing challenges in enhancing engineering education practice conducted by the ALTC Discipline Scholars for Engineering.

In addition, the recommendations for Transformational Change have informed discussion towards the development of an Australian Council of Engineering Deans (ACED) Discipline Network Support Scheme whose goals are the establishment of an Engineering LTN.

5.0 Evaluation

No formal evaluation of the project was conducted.

Audit

Emeritus Professor Robin King was appointed to audit the project. The final report will be forwarded to him as soon as possible.

6.0 Conclusions and recommendations

Conclusions

The following conclusions can be drawn out of the work of this project:

1. A clear consensus was expressed for the goal of achieving a three-dimensional engineering graduate that reflects a more balanced development of the PE1/PE2/PE3 competencies than is currently the case. This consensus came from a shared understanding arrived at conjointly by the three key stakeholders within the context of the first ALTC Forum, emerging from a qualitative analysis of the workshop activity responses, an extensive review of the literature as well as manifesting itself as the central discussion theme throughout the project.

2. There is a significant lack of integration within the curriculum between the teaching and learning of Engineering Science and of Engineering Design across the four institutions. The delivery of Engineering Science Learning Outcomes are firmly anchored to an outmoded, traditional, content-laden, theory-oriented model of teaching, with Engineering Design courses serving as bolt-on vehicles for attaining the bulk of the EA engineering ability PE2, and professional PE3 competencies through integrative learning experiences representative of pedagogical best practice in higher education.

3. Findings from the student focus groups strongly suggest that students value authentic, deep learning experiences, and that they perceive that the overly heavy emphasis in the curriculum on traditionally delivered engineering science fundamentals is inadequate for graduating them as engineers. There is little evidence that the traditional engineering science courses have adopted teaching practices that address the attainment of engineering ability competencies or that they will into the future. The data suggests that the majority of Engineering Science lecturers interviewed could not envision alternative ways of teaching their unit.

4. The barriers to achieving a curriculum that is more strongly defined around engineering problem solving, application and practice that is embedded in the themes of design and experienced in authentic, active learning modes appear to be primarily pedagogical, institutional and epistemological. These three dimensions are also strongly inter-connected within the culture of the discipline.

5. There is however, one positive indication which will inform the recommendations resulting from this project. Previous ALTC projects such as *"The B factor project: understanding academic staff beliefs about graduate attributes"* have similarly concluded that while there was evidence of positive beliefs and thus willingness/support for the inclusion of (in this case, graduate attributes within the curriculum) there is less evidence of concrete actions supporting these beliefs. The willingness by the three stakeholders (industry/academics/students) to participate in the first forum in our project combined with the willingness expressed by industry stakeholders to engage with universities to provide authentic professional practice experiences within the curriculum strongly suggests the need for strategies that can capitalise on this towards re-designing the curriculum in engineering.

    a. NOTE: The conclusion that there is an underlying willingness by academics for curriculum change is also supported by recent statistical evidence acquired by the ALTC Discipline Scholars for Engineering in a nationwide survey of engineering academics.

Recommendations

The primary and over-arching recommendation emanating from this project is to adopt a transformational change objective through strategies that are pursued concurrently from top-down (strategic/executive) and bottom-up (operational/academic) directions (Reidsema, Hadgraft, Cameron, King 2011). The aims of this transformational change approach are to focus on, and strengthen the following three dimensions of change which arose from the second ALTC workshop within this project:

1. Advocacy at the National level.
2. Engagement with Industry within the curriculum
3. Recognition of Teaching and Learning commensurate with Research

In pursuing these three dimensions we recommend the formation of a national guiding coalition of educational leaders, which has carriage of this transformational change that will address the strategic and tactical levels of partner institutions (Engineering Faculties). Specifically, this nationally distributed group of people will provide a substantive leadership role across institutions and at the national level. It will focus on establishing the sense of urgency in partnership with demonstrated engineering educational leaders at the operational level as well as with external stakeholders such as EA and selected industry representatives.

This nationally distributed group of people will act as a network of change agents and be derived from previous and existing ALTC projects in engineering education. Each educational leader will head up a specific portfolio (for example, design, teamwork, online learning, industry engagement etc..) and be tasked with forming teams of experts who will act as local, regional and national pedagogical assistance teams. These teams will engage with targeted areas at the operational level of partner institutions to foster and provide support to teaching academics helping to facilitate the uptake of new pedagogies and the use of best practice engineering education techniques and tools. This mode of "face-to-face" direct engagement leverages the expressed willingness of academics to engage with other academics from outside their institutions.

In order to pursue these objectives we will need strategic (executive), tactical (ADTL/Heads) and operational (course coordinator) interfaces in order to formulate a collective and agreed vision, agree on change targets, implement best practice across the sector and consolidate gains provided by the ALTC funding. Currently, steps are in progress through collaborations with Professor Robin King and Dr. Tony Koppi as part of the Australian Engineering and ICT Education Support Network funded by the ALTC.

To gain an insight into the acceptability of the primary recommendations of this project and strategic barriers to change, the remaining funds will be used to conduct a series of structured interviews with the Deans, Associate Deans of Teaching and Learning and selected academic staff of 16 Engineering Faculties in Australia in collaboration with Professor Ian Cameron who is the outgoing ALTC Discipline Scholar. An analysis of the results of these interviews will be presented at a workshop/forum that will include delegates from national advocacy bodies including ANET, ACED, ATSE, Engineers Australia, Industry, Associate Deans of TL and previous holders of ALTC grants with selected institutional leaders (100 people) to formulate action plans for the envisaged Australian Engineering Learning and Teaching Network.

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8.0 Appendices

Appendix 1:

Results and commentary from the data analysis: Unit outline analysis; interviews with engineering lecturers (16 Engineering lecturers from four universities); interviews with student focus groups (3 focus groups from 3 of the 4 participating universities); ATI (approaches to teaching inventory) responses: (16 Engineering lecturers from four universities); Forums 1, 2 and 3 (regional forums held to involve all stakeholders in the engineering community).

In order to triangulate the data investigating academics' beliefs and attitudes to teaching and learning, three different approaches were used:

1. **Unit outline analysis**

The engineering design units and engineering science unit outlines were analysed across the four universities. These outlines were obtained from the web pages of the four universities. The unit outlines were analysed for constructive alignment between learning activities, teaching activities, assessment tasks and types. They were also mapped against the Engineers Australia Graduate Attributes (2009), using both the equivalent graduate attributes as stated in the unit outline and the researcher's evaluation of the stated learning outcomes. In several cases, unit outlines claimed to develop graduate attributes but no evidence of this was found in the learning outcomes, the teaching and learning activities or in the assessment tasks.

a. **Overview of results**

In total, 24 unit outlines were analysed from the four universities: 12 from the Design strand of mechanical engineering and 12 from the Engineering Science strand – mainly but not always from mechanical engineering, for a number of reasons. For example, several units were taught across a number of programs, or programs were undergoing restructuring and so unit outlines were not available.

The engineering design units, in general, had quite strong constructive alignment between learning outcomes and teaching/learning activities and assessment types and tasks. There was more emphasis on continuous assessment, and on project-based learning: the majority of the units included a team project (assessment task information not available for two of the units), and six of the 12 units analysed did not have a final exam. The opportunity for authentic learning experiences, such as site visits, tool training and design-build projects was also notable in the unit outlines available for analysis. The graduate attributes developed in the engineering design units were heavily weighted towards engineering ability/professional attributes rather than knowledge base: the ratio was approximately 4:1.

The engineering science units were more varied in the degree to which there was constructive alignment between learning outcomes and teaching/learning activities and assessment types and tasks. Where there was strong constructive alignment, it tended to be very content-focused and assessed mainly by quizzes and exams. All the engineering science units had a final exam of 60% or more. An example of a learning outcome with strong constructive alignment is given by way of illustration: *Derive, from first principles, the Navier-Stokes equations and adapt these principles to a wide variety of fluid mechanics problems. Lectures & tutorials. Quiz 18% Assignment 12% Final Exam 60%* (University 4).

For several of the stated learning outcomes in a number of the unit outlines there were assessment tasks but no teaching or learning activities, for example: *effective communication in a variety of contexts and modes* – assessed by assignment and exam (University 1). For others, there was no assessment, teaching or learning activity, for example: *Create and develop "engineers' eyes"* (University 3), while there were also examples of claimed graduate attributes being developed that did not appear to have a learning outcome, learning activity, teaching or assessment component, such as: *ability to undertake problem identification, formulation & solution* (University 3). There was considerably less opportunity for authentic learning experiences in the engineering science units: while the majority of units had timetabled laboratory sessions, the students were often in the role of observer, as tutors or lab assistants demonstrated the experiments. This was generally due to very large class sizes, limited lab spaces, limited numbers of teaching assistants and OH & S concerns (as revealed in the lecturer and student focus group interviews). One of the 12 engineering science units had a design-build project, (University 1) and one had a site visit (University 1); all the other units had neither. Not surprisingly, the majority of the stated graduate attributes to be developed in these units focused on knowledge base, with some inclusion of engineering ability, predominantly in the area of: *undertake problem identification, formulation and solution.* As noted previously, when the unit outlines claimed to develop professional attributes, it was difficult to find where these were part of a learning outcome, a teaching/learning activity or an assessment task.

2. Interviews with engineering lecturers

16 engineering lecturers were interviewed across the four participating universities; at each university one engineering design lecturer and three engineering science lecturers were invited to be interviewed. The engineering science subjects chosen were: fluid dynamics, mechanics of solids and thermodynamics (Lucena 2003: 421), as these are seen as being core to a mechanical engineering program. Of those asked, almost all accepted without reservation. Two lecturers were unable to be interviewed due to other commitments, but other colleagues in the same teaching areas then volunteered. The interviews were semi-structured around 14 questions (a copy of the questions is included at the end of this appendix), and were recorded using a smartpen. The interviews were then transcribed verbatim and analysed thematically by the lead researcher and through Nvivo by an assistant researcher. The findings have been reported on extensively in a number of conference and journal papers (*Designing the Future; Perspectives on teaching and learning engineering across four universities; Best practice or business as usual?*) and so will be summarised here.

a. Overview of results

There were clear differences about epistemological beliefs between the engineering design and the engineering science lecturers, with the former group valuing experiential, contextualised and hands on learning, whereas the latter group regarded theoretical knowledge as paramount, especially knowledge that could be measured by individual performance in final examinations. These differences are demonstrated in the following areas: teaching and learning activities, types and weightings of assessment tasks and most important learning outcomes, and are supported by the unit outline analysis. Responses from the student focus group interviews reflected a desire for more authentic learning experiences (hands-on activities, site visits, videos of real-life engineering practice, design-build projects), a high regard for good teaching and frustration with not having sufficient opportunities to contextualise their theoretical knowledge. Some sample responses from the interviews are included here to give an indication.
Gaps in perception about the importance of what is taught:

b. 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

c. 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.

d. The responses from student focus groups included:

(QLD)
A: I would say, working with Australian standards which you do at work all the time.
B: I would have to say from our side, it was not working with Australian standards:
C: I think applying things from the classroom to an actual project, because a lot of the time they talk about them but you don't really

(NSW)
I think one of the common things that I guess are developed in these subjects, particularly the design ones is you know visualisation, like sketching, and being able to convey what you're thinking in diagrams and good clear sized diagrams, and that's both in thermodynamics where there is the analysis of a system – you know, show the heat in here – or in mechanics of solids, where you have forces of fluids, showing like all the fluid paths and all that. I think that's something that's particularly in common with all of them: they all require you to have like a basic level of good sketching, clear sketching, and I think you develop those in all those subjects.

(VIC)
Group work, group dynamics
[E] Applying the basic equations to practical problems that's one of the main things in tutes
[A] Application of theory to real life situations
[D] Application in a real world type of way so actually tackling the problem as an engineer tends to perform
[C] Turning big problems into several small problems – breaking it down and working in groups

3. ATI response analysis

The Approaches to Teaching Inventory, or ATI (Trigwell & Prosser 2004) was administered to all the engineering academics who were interviewed about their approaches to teaching, learning, course design and graduate attributes. After each semi-structured interview was conducted, the participant was asked to complete the ATI: a set of 16 statements 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. It should be noted that while the ATI is regarded by several authors to be a valid instrument (e.g. McKenna, Yalvac & Light 2009), it has also been strongly critiqued by Meyer and Eley (2006) in terms of its rigour and methodology. However, as it is used in this study only as one element of the triangulation of data, the question of validity is not critical to the whole study.

a. Overview of results

Despite the significant differences in course design between the engineering design lecturers and the engineering science lecturers, the responses to the ATI are not strongly differentiated by design/science strand. For almost all the statements, there was a similar spread of responses across the scale, allowing for proportional differences (4 engineering design academics: 12 engineering science academics). For three of the statements there was a noticeable difference in the responses from the design/science strands, although there was still a slight spread of responses:

Statement 10: *I structure this subject to help students to pass the formal assessment items*. Responses from the design strand were split between the lower end of the scale (rarely/sometimes), and the top end (almost always), whereas responses from the science strand clustered around the top end of the scale (nine out of 12 responses were at this end).

Statement 12: *In this subject, I only provide the students with the information they will need to pass the formal assessments.* The design strand responses were all at the lower end of the scale, while there was a spread of science strand responses to the middle/upper end.

Statement 16: *I feel a lot of teaching time in this subject should be used to question students' ideas.* The design strand had a spread of responses from **sometimes** to **frequently**; in contrast ten of the 12 responses from the science strand were **rarely** or **sometimes**.

Although it is not possible to make conclusive statements based on the data, it could be inferred that there is less emphasis on teaching to the formal assessment items in the design strand than in the science strand (remembering that all the engineering science units had final exams as 60% or more of the assessment weighting) and that there was less willingness to question students' ideas in the science strand. However, there would need to be more in-depth investigation and a broader sample of interviewees in order to draw firm conclusions from the current data.

A copy of the inventory and of the responses is included in the appendix.

4. Forums 1, 2 and 3.

As part of the broader investigation and dissemination of the intended aims of the project, three forums were held at various stages.

a. Forum 1

Forum 1, was a two-day event held in April 2009, at UNSW, with approximately 100 participants – 40 from industry, 40 from academia and 20 from the student engineering cohort at UNSW and USyd. The purpose of this forum was to involve all the stakeholders in discussions around current and future needs of the engineering community, and the ways in which the current and future engineering curricula can meet these needs. Several of the findings from this forum have been reported on in conference papers (*Designing the Future; Perspectives on teaching and learning engineering across four universities; Best practice or business as usual?*); two tables have been reproduced here to give an indication of the activities and findings.

From forum 1: desired graduate attributes

Table 4 Activity 3: top 6 graduate capabilities (*From Designing the Future)*

	%	CDIO	capabilities
1	26%	2.4	personal skills & attitudes
2	19%	3.2	communication
3	17%	4.4	designing
4	14%	3.1	teamwork
5	12%	2.3	systems thinking
6	12%	4.3	conceiving & designing engineering systems

Also from Forum 1: industry willingness to participate in the engineering curriculum (strategies suggested in group workshops)

Table 2: Strategies to overcome lack of engagement with industry in the current Australian engineering curriculum (*From Best Practice or business as usual?*)

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

b. Forum 2

Forum 2 was held in Brisbane in November 2010 and involved 40 participants from local and national industries as well as leading academics from around Australia, who were asked to consider models for change that would address the gap between theory and practice, develop authentic learning experiences for students and encourage engagement between industry, academics and students. Through the group activities, participants decided on three key projects to achieve the models for change**: Advocating engineering education reform nationally; professionalising engineering education; university/industry collaboration; developing a national centre for engineering education**

These key projects then formed the focus of **Forum 3.**

c. Forum 3

Forum 3 was held as a workshop at the annual national engineering education conference: AaEe 2010 at UTS, Sydney in December 2010. Workshop participants formed interest groups around each of the key projects and discussed ways of moving forward on each project, for example: forming an industry-university hub by using existing networks such as CEED; liaising with national bodies such as ATSE to develop a national engineering education centre and to raise the profile of engineering education at a federal level; and developing engineering education research through research scholarships.

SEMI-STRUCTURED INTERVIEW (SSI) QUESTIONS (for ALTC Project)

Demographic Learning outcomes Learning outcomes Learning activities Assessment Assessment Reflections Attitudes to grad caps Attitudes to grad caps Knowledge of outcomes of grad caps Awareness of constructive alignment Attitudes to change	How many students are there in this unit of study? What is the usual number of students in this unit? At what level of competency do you think students are when they enter your unit? What are the most important things (limit 5?) that students learn in your unit? How do the students learn in your class? What are the best ways of measuring student learning in your unit? How did you decide on the weighting of the various assessment tasks? *What is the purpose of the exam in your unit?* **n.b. only to be used if the unit has an exam** How does your unit fit in with the program as a whole? What is your understanding of the role of graduate competencies/attributes/capabilities? To what extent do you think that lecturers are responsible for developing graduate competencies in students? *At what level are the graduate competencies taught in your UoS? (e.g. beginning, intermediate, advanced) and how do you decide on the level?* **n.b. only to be used if the unit outline specifies levels** Can you identify any gaps in your unit outline around any of the learning outcomes or competencies? Can you add any information about why the gaps are there? Do you enjoy your teaching? If you had all the time and resources at your disposal, how would you design this unit? What changes would you make? Would you make any changes in the way this unit is assessed?

GUIDE TO ASSESSMENT OF ELIGIBILITY FOR MEMBERSHIP **(STAGE 1** COMPETENCY)

AUSTRALIAN ENGINEERING COMPETENCY STANDARDS - STAGE 1 COMPETENCY STANDARDS FOR PROFESSIONAL ENGINEERS

GENERAL DESCRIPTION OF ROLE

Professional engineers are required to take responsibility for engineering projects and programs in the most far-reaching sense. This includes the reliable functioning of all materials and technologies used; their integration to form a complete and self-consistent system; and all interactions between the technical system and the environment in which it functions. The latter includes understanding the requirements of clients and of society as a whole; working to optimise social, environmental and economic outcomes over the lifetime of the product or program; interacting effectively with the other disciplines, professions and people involved; and ensuring that the engineering contribution is properly integrated into the totality of the undertaking. Professional engineers are responsible for interpreting technological possibilities to society, business and government; and for ensuring as far as possible that policy decisions are properly informed by such possibilities and consequences, and that costs, risks and limitations are properly understood as the desirable outcomes.

Professional engineers are responsible for bringing knowledge to bear from multiple sources to develop solutions to complex problems and issues, for ensuring that technical and non-technical considerations are properly integrated, and for managing risk.

The work of professional engineers is predominantly intellectual in nature. In the technical domain, they are primarily concerned with the advancement of technologies and with the development of new technologies and their applications through innovation, creativity and change. They may conduct research concerned with advancing the science of engineering and with developing new engineering principles and technologies. Alternatively, they may contribute to continual improvement in the practice of engineering, and in devising and updating the Codes and Standards that govern it.

Professional engineers have a particular responsibility for ensuring that all aspects of a project are soundly based in theory and fundamental principle, and for understanding clearly how new developments relate to established practice and experience and to other disciplines with which they may interact. One hallmark of a professional is the capacity to break new ground in an informed and responsible way.

Professional engineers may lead or manage teams appropriate to these activities, and may establish their own companies or move into senior management roles in engineering and related enterprises.

STAGE 1 COMPETENCY

Stage 1 competency represents the level of preparation necessary and adequate for entry to practice leading to these responsibilities. A graduate engineer would be expected to work initially under the supervision and guidance of more experienced engineers, while experience is gained. Graduate engineers are encouraged to undertake Professional Development Programs approved by Engineers Australia while developing the practice competencies that will qualify them for Stage 2 assessment and the status of Chartered Professional Engineer.

A Stage 1 Professional Engineer is expected to demonstrate competence across a broad field of engineering practice, or engineering discipline, and to have a good understanding of interfaces with other engineering disciplines. An accredited professional engineering degree program must develop breadth of understanding and outlook, and ability to engage with a wide range of technologies and applications, with sufficient depth in one or more specific areas of practice to develop competence in handling technically advanced and complex problems.

Well-established engineering disciplines include, for example, civil, chemical, computer systems, electrical and electronic, and mechanical engineering. Engineers Australia recognises, as equally valid, programs and competencies that span two or more of the traditional disciplines: for example aerospace, environmental, mechatronics, software, and telecommunications engineering. The term engineering discipline is used in these standards to denote any such broad field of engineering practice.

Stage 1 competency corresponds to completion of a 4-year Bachelor of Engineering degree accredited by Engineers Australia. The *Manual for the Accreditation of Professional Engineering Programs* provides guidance on the topics and subject areas expected to be covered in particular engineering disciplines. It is not expected that candidates will have demonstrated every detail of the knowledge, competencies and attributes that follow; but they must demonstrate at least the substance of each element. Assessment will be made in a holistic way.

PROFESSIONAL ENGINEER STAGE 1: UNITS AND ELEMENTS OF COMPETENCY

Units are numbered PE1, PE2 etc. Elements are numbered PE1.1, PE1.2 etc
Indicators are denoted by a, b, c etc

PE1 KNOWLEDGE BASE

PE1.1 Knowledge of science and engineering fundamentals

a. Sound knowledge of mathematics to the level required for fluency in the techniques of analysis and synthesis that are relevant to the broad field of engineering, and to potentially related fields
b. Sound basic knowledge of the physical sciences, life sciences, and information sciences underpinning the broad field of engineering and potentially related fields, and appreciation of scientific method
c. Strong grasp of the areas of engineering science that support the broad field of engineering
d. Ability to work from first principles in tackling technically challenging problems

PE1.2 In-depth technical competence in at least one engineering discipline

a. Knowledge of the major technical areas comprising least one engineering discipline, and competence in applying mathematics, science and engineering science to the analysis and solution of representative problems, situations and challenges in those areas
b. Knowledge of materials and resources relevant to the discipline, and their main properties, and ability to select appropriate materials and techniques for particular objectives
c. Awareness of current technical and professional practice, critical issues, and the current state of developments in the major technical areas that constitute the discipline
d. Advanced knowledge in at least one area within the discipline, to a level that engages with current developments in that area; understanding of the relevant techniques and ability to apply them to representative problems and situations to a significant level of technical complexity and challenge
e. Ability to ensure that all aspects of a project or program are soundly based in theory and fundamental principles and to recognise results, calculations or proposals that may be ill-founded, identify the source and nature of the problem and take corrective action
f. Understanding of how new developments relate to established theory and practice, and to other disciplines with which they may interact

PE1.3 Techniques and resources

a. Ability to develop and construct mathematical, physical and conceptual models of situations, systems and devices, ability to utilise such models for purposes of analysis and design, and understanding of their applicability and shortcomings
b. Ability to characterise materials, devices and systems relevant to the broad field and related fields
c. Awareness of current tools for analysis, simulation, visualisation, synthesis and design, particularly computer-based tools and packages, and competence in the use of a representative selection of these
d. Appreciation of the accuracy and limitations of such tools and the assumptions inherent in their use; ability to verify the credibility of results achieved, preferably from first principles, to a reasonable approximation
e. Proficiency in a substantial range of laboratory procedures in the discipline, and strong grasp of principles and practices of laboratory safety
f. Ability to design and conduct experiments, devise appropriate measurements, analyse and interpret data and form reliable conclusions
g. Ability to perceive possible sources of error, eliminate or compensate for them where possible, and quantify their significance to the conclusions drawn
h. Ability to construct and test representative components or sub-systems in a laboratory setting

PE1.4 General Knowledge

a. Broad educational background and/or general knowledge necessary to understand the place of engineering in society

PE2 ENGINEERING ABILITY

PE2.1 Ability to undertake problem identification, formulation, and solution

a. Ability to identify the nature of a technical problem, make appropriate simplifying assumptions, achieve a solution, and quantify the significance of the assumptions to the reliability of the solution
b. Ability to investigate a situation or the behaviour of a system and ascertain relevant causes and effects
c. Ability to address issues and problems that have no obvious solution and require originality in analysis
d. Ability to identify the contribution that engineering might make to situations requiring multidisciplinary inputs (see also PE2.2 and PE2.3) and to recognise the engineering contribution as one element in the total approach

PE2.2 Understanding of social, cultural, global, and environmental responsibilities and the need to employ principles of sustainable development

a. Appreciation of the interactions between technical systems and the social, cultural, environmental, economic and political context in which they operate, and the relationships between these factors
b. Appreciation of the imperatives of safety and of sustainability, and approaches to developing and maintaining safe and sustainable systems
c. Ability to interact with people in other disciplines and professions to broaden knowledge, achieve multidisciplinary outcomes, and ensure that the engineering contribution is properly integrated into the total project
d. Appreciation of the nature of risk, both of a technical kind and in relation to clients, users, the community and the environment

PE2.3 Ability to utilise a systems approach to complex problems and to design and operational performance

a. Ability to engage with ill-defined situations and problems involving uncertainty, imprecise information, and wide-ranging and conflicting technical and non-technical factors
b. Understanding of the need to plan and quantify performance over the life-cycle of a project or program, integrating technical performance with social, environmental and economic outcomes
c. Ability to utilise a systems-engineering or equivalent disciplined, holistic approach to incorporate all considerations
d. Understanding of the process of partitioning a problem, process or system into manageable elements, for purposes of analysis or design; and of re-combining these to form the whole, with the integrity and performance of the overall system as the paramount consideration
e. Ability to conceptualise and define possible alternative engineering approaches and evaluate their advantages and disadvantages in terms of functionality, cost, sustainability and all other factors
f. Ability to comprehend, assess and quantify the risks in each case and devise strategies for their management

g. Ability to select an optimal approach that is deliverable in practice, and justify and defend the selection
h. Understanding of the importance of employing feedback from the commissioning process, and from operational performance, to effect improvements

PE2.4 Proficiency in engineering design

a. Proficiency in employing technical knowledge, design methodology, and appropriate tools and resources to design components, systems or processes to meet specified performance criteria
b. Experience in personally conducting a variety of such designs typical of the engineering discipline
c. Experience in personally conducting a major design exercise to achieve a substantial engineering outcome to professional standards, demonstrating capacity to:

• elicit, understand and document the required outcomes of a project and define acceptance criteria
• consider the impact of all development and implementation factors including constraints and risks
• write functional specifications, using engineering methods and standards, that meet the user requirements
• seek advice from appropriate sources, including advice on latest applicable technologies
• identify and analyse possible design concepts, and propose and agree optimal solution
• ensure that the chosen solution maximises functionality, safety and sustainability, and identify any possibilities for further improvement
• develop and complete the design or plan using appropriate engineering principles, resources, and processes
• specify the equipment and operating arrangements needed
• ensure integration of all functional elements to form a coherent, self-consistent system; check performance of each element and of the system as a whole
• check the design solution against the engineering and functional specifications
• quantify the engineering tasks required to implement the chosen solution
• devise and document tests to verify performance and take any corrective action necessary

d. Alternatively, experience as a member of a team conducting such a major design exercise, and ability to demonstrate a key contribution to the team effort and the success of the outcome

PE2.5 Ability to conduct an engineering project

a. Experience in personally conducting and managing an engineering project to achieve a substantial outcome to professional standards, or as a member of a team conducting such a project, and ability to demonstrate a key contribution to the team effort and the success of the outcome
A Stage 1 graduate should have undertaken and completed two or more practical engineering projects; at least one investigative project and at least one major design project. At least one substantial project should be conducted individually, and at least one as part of a team. Accredited degree programs should provide and require such project work for all students. The report of engineering workplace experience during undergraduate vacation periods would be acknowledged.
b. Understanding of project management techniques and ability to apply them effectively in practice
c. Have produced at least one major report demonstrating mastery of the subject matter and ability to communicate complex material clearly to both technical and lay readers

PE2.6 Understanding of the business environment

a. Introductory knowledge of the conduct and management of engineering enterprises and of the structure and capabilities of the engineering workforce
b. Appreciation of the commercial, financial, and marketing aspects of engineering projects and programs and the requirements for successful innovation
c. Ability to assess realistically the scope and dimensions of a project or task, as a starting point for estimating costs and scale of effort required
d. Understanding of the need to incorporate cost considerations throughout the design and execution of a project and to manage within realistic constraints of time and budget
e. General awareness of business principles and appreciation of their significance

PE3 PROFESSIONAL ATTRIBUTES

PE3.1 Ability to communicate effectively, with the engineering team and with the community at large

a. High level of competence in written and spoken English
b. Ability to make effective oral and written presentations to technical and non-technical audiences
c. Capacity to hear and comprehend others’ viewpoints as well as convey information
d. Effectiveness in discussion and negotiation and in presenting arguments clearly and concisely
e. Ability to represent engineering issues and the engineering profession to the broader community

PE3.2 Ability to manage information and documentation

a. Ability to locate, catalogue and utilise relevant information, including proficiency in accessing, systematically searching, analysing and evaluating relevant publications
b. Ability to assess the accuracy, reliability and authenticity of information
c. Ability to produce clear diagrams and engineering sketches
d. Fluency in current computer-based word-processing and graphics packages
e. Ability to maintain a professional journal and records and to produce clear and well-constructed engineering documents such as progress reports, project reports, reports of investigations, proposals, designs, briefs, and technical directions

f. Awareness of document identification and control procedures

PE3.3 Capacity for creativity and innovation

a. Readiness to challenge engineering practices from technical and non-technical viewpoints, to identify opportunities for improvement

b. Ability to apply creative approaches to identify and develop alternative concepts and procedures

c. Awareness of other fields of engineering and technology with which interfaces may develop, and openness to such interactions

d. Propensity to seek out, comprehend and apply new information, from wide range of sources

e. Readiness to engage in wide-ranging exchanges of ideas, and receptiveness to change

PE3.4 Understanding of professional and ethical responsibilities, and commitment to them

a. Familiarity with Engineers Australia's Code of Ethics, and any other compatible codes of ethics relevant to the engineering discipline and field of practice, and commitment to their tenets

b. Awareness of legislation and statutory requirements relevant to the discipline and field of practice

c. Awareness of standards and codes of practice relevant to the discipline and field of practice

PE3.5 Ability to function effectively as an individual and in multidisciplinary and multicultural teams, as a team leader or manager as well as an effective team member

a. Manage own time and processes effectively, prioritising competing demands to achieve personal and team goals and objectives

b. Earn trust and confidence of colleagues through competent and timely completion of tasks

c. Communicate frequently and effectively with other team members

d. Recognise the value of diversity, develop effective interpersonal and intercultural skills, and build network relationships that value and sustain a team ethic

e. Mentor others, and accept mentoring from others, in technical and team issues

f. Demonstrate capacity for initiative and leadership while respecting others' agreed roles

PE3.6 Capacity for lifelong learning and professional development

a. Recognise limits to own knowledge and seek advice, or undertake research, to supplement it

b. Take charge of own learning and development; understand the need to critically review and reflect on capability, invite peer review, benchmark against appropriate standards, determine areas for development and undertake appropriate learning programs

c. Commit to the importance of being part of a professional and intellectual community: learning from its knowledge and standards, and contributing to their maintenance and advancement

d. Improve non-engineering knowledge and skills to assist in achieving engineering outcomes

PE3.7 Professional Attitudes

a. Present a professional image in all circumstances, including relations with clients, suppliers and stakeholders as well as professional and technical colleagues

b. Demonstrate intellectual rigour and readiness to tackle new issues in a responsible way

c. Demonstrate a sense of the physical and intellectual dimensions of projects and programs, and related information requirements, based on reasoning from first principles and on developing experience

Subreport for The University of Melbourne

Developing a Supportive Teaching Materials Website

Design-based curricula, relying as they do on project-based learning, put more demands on students to find their own learning resources. There are several international repositories that catalogue learning resources in engineering and many other disciplines, including Engineering Pathway and MERLOT (see http://aaee-scholar.pbworks.com/w/page/1177059/Global-sites#view=page).

It became obvious to the project team that academics and students need a filtered list of resources, rather than having to troll through hundreds of thousands of hits on some of the large repositories (Hadgraft 2007).

A start has been made on gathering together resources with a focus on the engineering fundamentals such as solid mechanics, fluid mechanics, thermodynamics, etc. The site has been developed in conjunction with AAEE as http://aaee-scholar.pbworks.com with the following main menu:

Workshops and Conferences

Special Interest Groups (SIGs)

Bibliography (what you should read in Engineering Education)
Engineering Basics (Resources) - from the ALTC projects and elsewhere
Graduate Certificate resources
Journal ranking for the ERA process

Opening page

The opening page is as follows, providing links to the general sites and then to the fundamental materials. Some individual pages are documented here for to give a flavor for the resources assembled.

General
Global sites with many resources
See also the Bibliography

Basics
Introduction to Engineering
Engineering Mathematics (Feb 10)
Calculus
Physics
Computing skills

Engineering sciences
Engineering Mechanics (14 June 10)
Engineering Materials (3 July 09)
Fluid Mechanics (13 Dec 10)
Mechanical Systems (3 July 09)
Thermodynamics (2 July 10)
Earth Processes for Engineering (3 July 09)
Electrical circuits and systems (13 Apr 10)

Applications
PLC Programming & Simulator (Ladder Logic etc) - a free package from TRiLOGi
ASME resources

Professional skills
Engineering ethics (US National Academy of Engineering)

These resources have been assembled by the ALTC Discipline Scholars, Roger Hadgraft and Ian Cameron, including input from other ALTC projects, such as the CDIO-Design Based Curriculum project at UNSW, led by Carl Reidsema. These are useful resources for teaching the **fundamentals of engineering**.

If you know of other good sites, please contact Roger Hadgraft. You could start your own pages for the subjects that you teach.

Another useful tool is Delicious. Just tag your favourite sites using standards tag and they'll be accessible here.

The **Bibliography** was a parallel activity conducted by the AAEE community to document key readings related to engineering education. It covers these topics:

Professional Standards and Accreditation
What is Learning?
Curriculum Design
Teaching Methods
Assessment
Diversity
Multidisciplinary
The Journey (from teacher to scholarly researcher)
Teaching and Learning Centres

Introduction to Engineering

The Project Handbook

what you need to know to become an effective project team member - http://project-handbook.pbworks.com

Teamwork (via the Project Handbook site) - http://project-handbook.pbworks.com/w/page/18981702/Teamwork

Engineering Design Process

– a visual and simple explanation of the design process - http://www.mos.org/eie/engineering_design.php

Sustainability

Resources and links- from The Natural Edge Project

also, the Sustainable development encyclopedia, everything you need to know about sustainable development - http://www.ace.mmu.ac.uk/esd/menu.html

Computing skills

Getting started tutorials in a range of computing tools

Fun and Games (Engineering style)

Links to many fun and interesting engineering games that use realistic physics principles and design processes, which force the player to think in order to win http://www.tryengineering.org/play.php

Engineering Mathematics

General resources

Maths resources at the UK Math Centre

Laplace transforms

Interactive mathematics site which has explanations and then questions, with worked examples http://www.intmath.com/Laplace-transformation/Intro.php

Laplace transformations quiz (but no worked answers) http://www.ee.adfa.edu.au/staff/hrp/Quiz/control/L1-quiz.html

ODEs

Phase Portraits for ODEs and Autonomous systems with ability to input systems http://www.math.psu.edu/melvin/phase/newphase.html

Fourier series and transforms

Explanation and worked examples of Fourier series representations, with moving diagrams showing how it estimates a line of best fit over a function: http://www.sosmath.com/fourier/fourier1/fourier1.html

An application that helps to explain a practical use of Fourier series representations http://www.falstad.com/fourier/

References

Hadgraft, R. G. (2007). It's time for a coordinated approach to computer-aided learning and assessment. Australasian Assoc. for Eng Educ. Annual Conference. Melbourne, The University of Melbourne: paper 64.

Berkeley, Statics: http://bits.me.berkeley.edu/cw/00/02/36/1/static.exe
Buffalo, Interactive Structures: http://www.learningstructures.org/home.asp (Structures for architects and designers)
Delicious: http://delicious.com/tag/statics+engineering (Lots and lots of additional links)
eFunda, Engineering Fundamentals: http://www.efunda.com/formulae/formula_index.cfm (Basic mechanics)
John Hopkins, Truss designer: http://www.jhu.edu/~virtlab/bridge/truss.htm (Web-based software)
Missouri-Rolla, Engineering Mechanics: http://web.mst.edu/~oci/index.html (Statics & dynamics)
Missouri State, Virtual Laboratory for Structural Mechanics: http://www.ae.msstate.edu/vlsm/
MIT
Engineering Mechanics of Solids http://ocw.mit.edu/OcwWeb/Civil-and-Environmental-Engineering/1-050Fall-2004/CourseHome/index.htm
Active Statics demonstrations: http://ocw.mit.edu/ans7870/4/4.461/f04/module/Start.html
Includes TrussWorks and FrameWorks software.
Nebraska, Lincoln
Mechanics Source page http://em-ntserver.unl.edu/
Statics, dynamics, mechanics of materials; supporting maths
Ohio
Statics http://www.ent.ohiou.edu/~statics/

Oklahoma
Fundamentals of Engineering Review http://www.feexam.ou.edu/
Statics, dynamics, mechanics, materials, thermo, fluids, maths, economics, ethics, electrical, computers, chemistry
OU Engineering Media Lab
http://www.ecourses.ou.edu/
Statics; Dynamics; Fluids; Thermodynamics; Math - Calculus; Mechanics ; MEMS; Multimedia
Purdue
Statics http://www.engr.iupui.edu/~zecher/soft.html
Downloadable multimedia
Rochester
Statics interactive tutorials http://people.rit.edu/pnveme/plig_2004/Statics/

South Carolina
Engineering Mechanics
http://www.gatewaycoalition.org/files/Engineering_Mechanics/index.html
Text & graphics
Virginia Tech
Engineering Applets http://www.engapplets.vt.edu/
Statics, dynamics, fluids, .etc

Subreport for The University of Sydney
Project Title: DESIGN BASED CURRICULUM REFORM WITHIN ENGINEERING EDUCATION

Activities at The University of Sydney
The University of Sydney participated in all four phases of this inter-institutional research program in accordance with the primary agreement with ALTC. The activities at The University of Sydney were led by CI Levy who will work in close liaison with the other CIs.
In particular, The University of Sydney shared with the other participating institutions its experience with its common first year, development of its CDIO curriculum, staff development, experience with developing engineering design through years 1-4, Introduction to Engineering and IT component and development of its approach to critical thinking in engineering education.

The University of Sydney is applying the emerging models and identified changes in significant curricula reform and delivery that emerge from this project.
The University of Sydney is contributing to the emerging **community of practice** with the partner institutions, participated in the **comparative studies** of the engineering curricula at the partner institutions, is participating in the design and development of the proposed Australian **engineering curriculum** based on CDIO principles, has made **examples of best practice available** to the partner investigators, shared its experience and provided explicit recommendations for the **implementation strategies** for the new curriculum and is assisting with the project **dissemination** strategy.

Project Program
Phase 1 (Conceive – understand the changes required): July 2008 to Dec 2008
During phase 1, The University of Sydney assisted with the design and development of the data collection program and with mapping and comparing the UNSW, UMelb, USyd, QUT engineering graduate attributes, curriculum structures, learning styles, outcomes and mechanisms to the CDIO Syllabus in accordance with the primary agreement.

Phase 2 (Conceive – understand the levers for change): Dec 2008 to June 2009
During phase 2 The University of Sydney continued to assist with the of mapping and comparison of UNSW, UMelb, QUT and USyd, Engineering Faculty graduate Attributes, curriculum structures, learning styles, outcomes and mechanisms to the CDIO Syllabus in accordance with the primary agreement. The resulting mapping is attached.

Phase 3 (Design – the change required): July 2009 to Dec 2009
During phase 3 The University of Sydney participated in the development of potential curriculum models and addressed the integration of in-depth technical and professional competencies using the curriculum maps and within the constraints identified in Phases 1 and 2 in accordance with the primary agreement. A full spreadsheet with automated analysis of The University of Sydney Electrical Engineering programs is available as a model and can be downloaded from the ALTC website.

The University of Sydney will continue its curriculum development and reform process based on the CDIO framework and the processes developed as part of this project and will share the outcome with other Universities.

Phase 4 (Implement – the change process): Dec 2009 to June 2010
The University of Sydney completed its implementation of its CDIO curriculum and has completed the third year of its implementation of its common first year. Student responses are

encouraging and feedback on these outcomes and will provide further input and incentive for staff development.

Budget

Research Assistance: for CI4: $20,000

A research assistant, Mr A Popp, was engaged to assist the CIs in data collection, interviews, analysis and local development activities including the curriculum mapping system. The funds were invoiced in two annual amounts of $10,000 in 2008 and 2009 and have been utilised in full.

Airfares/travel between Sydney, Melbourne and Brisbane.

One meeting was attended in Brisbane and invoiced to the project.

In-kind Contributions from Collaborators:

The University of Sydney provided in-kind contributions and overheads as indicated in the budget table in the primary agreement

D C Levy
CI4
2nd Dec 2010

General Notes:

This framework has been designed to compare two (2) or more curriculums, competency standards or course outlines. This has been made possible by the use of multi-layer groups which can be shown or hidden to suit.

The CDIO syllabus has been set on the left hand-side as the comparison driver, since it has been determined that this syllabus is the most complete when compared to other standards such as Engineers Australia NGCS (National Generic Competency Standards).

Each standard compared has been allowed three (3) columns, one for each level of detail. This seems to be appropriate as the taxonomy in most standards does not go beyond this level of detail.

Since the CDIO standards were the ones being compared against, each standard from the EA NGCS was compared according to possible counterparts in the CDIO standard at the respective level of detail.

Comparison Method (3rd level of detail):

When comparing a third level item in CDIO, say 2.1.1 'Problem Identification and Formulation', an attempt was made to find third level items from EA standards to match.

Multiple matches were allowed from the EA standards. For example, item 2.1.1 from CDIO framework has three (3) matches from the EA standards (i.e. PE 2.1.a and PE 2.4.c). Note that PE 2.4.c is a special case, as it is an extremely long item in the EA NGCS and has been broken up into more parts.

The strength of the match was also considered; strong matches are in black, while weak matches are in grey.

Comparison Method (2nd level of detail):

The second level did not involve a direct comparison to the CDIO standards, but is representative of an aggregation of the 3rd level matches. Where all 3rd level items were all weak relationships, these have not been aggregated upwards.

For example, if 'PE 2.1.a' and 'PE 2.1.d' were matches to CDIO items, then the level two comparison would show 'PE 2.1 – 2 times'.

The items have then been ordered in descending order to highlight the significance and representation of each.

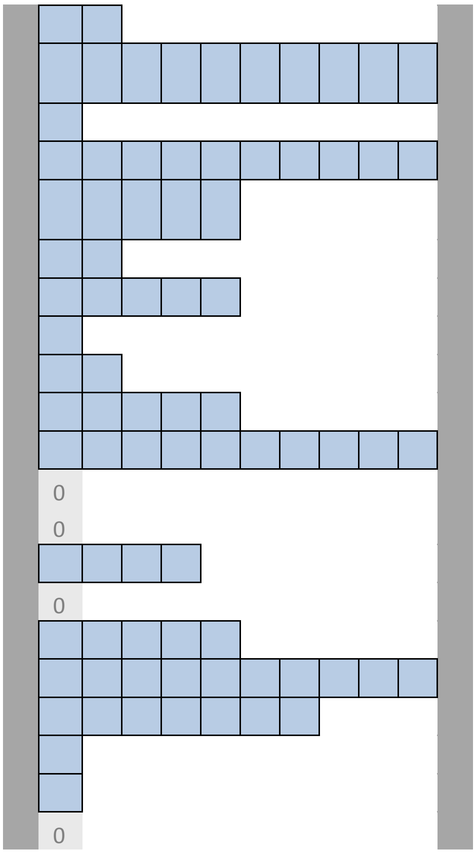
Comparison Method (1st level of detail):

Level one (1) was carried out in the same way as level two (2).

Table 1: An example of a Level 2 CDIO Mapping (USyd Mapping Tool)

U X.X   U X.X.X

Level 2 Mapping   SE Stream - X.X Map



U 1.1	Knowledge of underlying science and engineering fundamentals.
U 1.2	Core engineering fundamental knowledge in at least one engineering discipline.
U 1.3	Advanced engineering fundamental knowledge in at least one discipline.
U 2.1	Engineering reasoning and problem solving techniques.
U 2.2	Engineering experimentation and knowledge development techniques.
U 2.3	Holistic and multidisciplinary system approach.
U 2.4	Critical and innovative thinking and personal attitudes.
U 2.5	Professional Approach Elements
U 2.6	Leadership, Responsibility and Ethical Approach
U 3.1	Team working Elements
U 3.2	Communication Elements
U 3.3	Language Protocol
U 3.4	Leadership Elements
U 4.1	Natural and Societal Responsibilities and Constraints.
U 4.2	Corporate & Enterprise Environments.
U 4.3	Conceiving Systems, Processes or Products.
U 4.4	Elements of System, Process or Product Design.
U 4.5	Implementation Elements of Systems, Processes or Products.
U 4.6	Operational Elements of Systems, Processes or Products.
U 4.7	Management and Entrepreneurship Elements
U 4.8	Invention & Innovation

Subreport for Queensland University of Technology

QUT First Year Engineering Program Redevelopment

In 2010, QUT began running its new common first year program. The program was designed following the CDIO change management framework and adopting engineering design process, for the program design. Following the CDIO vernacular, QUT adopted four phases of program design:- Conceiving, Designing, Implementing and Operating. The program had a common set of design parameters, design principles , common learning and teaching approaches (listed below for the QUT context).

The keystone for integrating the first year learning outcomes is the introduction of the Introduction to Engineering Design unit, which now runs in second semester of the first year. The unit serves to provide the integration of the technical and theoretical aspects of the preceding and concurrent units, and the non-technical EA Professional Competencies. The learning outcomes for Introduction to Engineering Design are:-

1. Describe and demonstrate the basic processes by which engineering projects and systems are designed;
2. Use a modelling approach as part of the design and production of a simple system;
3. Communicate with the engineering team and the community at large to investigate and present

simple design solutions;
4. Demonstrate creative and innovative solutions in how you approach design tasks.

In 2010, around 600 students from all engineering discipline areas took the unit. Feedback was mixed for this initial offering, varying from an appreciation of the multi-disciplinary approach, the integration of the technical and non-technical professional competencies, the studio space focused learning environment, and the multi-disiplinary approach of the teaching team; to not appreciating the significance of the non-technical competencies, and the departure from conventional lecture/tutorial format, and mono-discipline topic areas. Particular challenges around the initial running of the program in 2010 include:- higher demand to University support mechanisms for the large scale multi-disciplinary approach to learning and teaching, and the management of a large teaching team in multi-disicplinary, studio space centred teaching – particularly for those who have had a more conventional mono-disciplinary engineering-science based education and not exposed to design processes in the workforce.

Community of Practice
The promotion of a community of practice occurred at two levels.

(i) QUT Foundation Discipline Team
Internal to QUT, the Engineering foundation discipline group was established to coordinate the implementation and operation phases of the integrated first year program. This community comprises the engineering unit coordinators, service unit coordinators (mathematics), and learning and teaching support professionals. This group ensures the coherency of the curriculum, learning outcomes, teaching practices, assessment and constructive alignment to ensure that the first year operated as a whole, not as a conglomeration of disparate units. The Introduction to Engineering Design unit forms a key point of integration within the first year program.

Every first year engineering unit also has fortnightly teaching staff developmental workshops which provide learning and teaching professional development and become a point of reflection and briefing for upcoming learning activities within the units,

(ii) CDIO Community of Practice
CI[DC] Led the establishment of the CDIO Special Interest Group within AAEE. Through this SIG, a web portal was established within the AAEE-Scholar Wiki which provided for local resources, local interests and connections to the global CDIO Community. Through the activities of the SIG, the ANZ CDIO Regional Chairs (CI[DC], CI[DL]), a series of AAEE Conference special sessions, and AAEE Special Workshops on CDIO and deign based curriculum reform, the CDIO community within Australia is growing. At the AAEE Conference in 2010, the "Fall" CDIO Collaborators meeting was co-hosted with the AAEE conference which brought many of the global CDIO leaders and collaborators to AAEE which served two purposes. Firstly, a number of introductory and advanced CDIO workshops were conducted within AAEE which provided attendees with an awareness, and the tools to implement aspects of CDIO as a basis for design based curriculum reform. Secondly, it demonstrated to the global CDIO collaborators the high standard of scholarship and research in engineering education within Australia (and New Zealand). It is hoped that many enduring relationships and collaborations emerge from this unique meeting of the communities.

Design Parameters
• Engineers Australia (EA) Accreditation Requirements and recommendations

Design Principles
• Transition: Curriculum must be consistent and explicit in assisting students' transition

Common Learning and Teaching Approaches
• A context/case based approach should be used to promote motivation to learn

- QUT First Year Curriculum Development Principles will be adopted.
- First year will be common to all EN40 Study Area A (Majors) – 8 units
- Introducing Professional Learning and Introducing Sustainability are to be included and scheduled in first year.
- Streaming will occur in second year into the Civil, Electrical & Mechanical Streams.
- The Applications Minor for each Study Area A will comprise the two capstone project units, one WIL unit and a selective unit .
- Incoming student capabilities will inform the program design and learning.
- Engineering and science fundamentals must be addressed in depth, delivered in interesting ways and encourage active learning for students (systems approach, context based, experiential, CDIO etc.)
- Threading of the University's Graduate Capabilities as well as EA's Graduate Attributes (including the competency standards) must be achieved through each course pathway.

from their previous educational experience to the nature of learning in higher education

- Diversity: Recognise that students have special learning needs by reason of their social, cultural and academic transition.
- Design: Curriculum must be designed to assist student development through the intentional integration and sequencing of knowledge, skills, and attitudes.
- Engagement: Learning, teaching, and assessment approaches in the first year curriculum should promote active and interactive learning opportunities.

the theories in the fundamental mathematics and engineering sciences.

- Tutorial classes must be interactive and engaging for the students with encouragement to learn from the peers.
- Tutorial classes will have direct relevance to the lecture and the assessment in the unit.
- Learning spaces must be conducive to the above approaches.
- Where possible, provide direct hands on experience to verify or learn some of the concepts.
- Clearly indicate the connection between the various units, not only the current ones but also the previously completed units as well as units coming later.

Graduate Attribute Mapping With the Extended CDIO Framework

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Abstract: The CDIO (Conceive-Design-Implement-Operate) Initiative has been globally recognised as an enabler for engineering education reform. With the CDIO process, the CDIO Standards and the CDIO Syllabus, many scholarly contributions have been made around cultural change, curriculum reform and learning environments. In the Australasian region, reform is gaining significant momentum within the engineering education community, the profession, and higher education institutions. This paper presents the CDIO Syllabus cast into the Australian context by mapping it to the Engineers Australia Graduate Attributes, the Washington Accord Graduate Attributes and the Queensland University of Technology Graduate Capabilities. Furthermore, in recognition that many secondary schools and technical training institutions offer introductory engineering technology subjects, this paper presents an extended self-rating framework suited for recognising developing levels of proficiency at a preparatory level. A demonstrator mapping tool has been created to demonstrate the application of this extended graduate attribute mapping framework as a precursor to an integrated curriculum information model.

Introduction

Worldwide, curriculum and cultural reform in engineering education is high on the agenda. Engineering skills have been shown to contribute directly to the global economy, environment, security and health. Engineering businesses seek engineers with abilities and attributes in two broad areas – technical understanding and generic graduate attributes. The first of these comprises: a sound knowledge of disciplinary fundamentals; a strong grasp of mathematics; creativity and innovation; together with the ability to apply theory in practice. The second is the set of attributes that enable engineers to work effectively in a business environment: communication skills; team working skills; and business awareness of the implications of engineering decisions and investments (Engineers Australia, 2006).

Over the past decade, Australian engineering schools have been innovative and responsive to students' and industry needs, while meeting the requirements of the professional accreditation bodies. Despite progress made by institutions, it remains a challenge to integrate these professional outcomes in engineering programs in a manner that prepares students for the professional complexities of their careers. This is due to traditional thinking about engineering curricula, and in a sense holding onto past messages (Rover, 2008). Felder and Brent point out that equipping students with necessary skills (graduate attributes) is much harder than determining whether or not they have these skills (Felder and Brent, 2003).

Australian engineering schools have maintained good international educational standards by a combination of mechanisms, including international benchmarking, international staff recruitment, student and staff exchanges, and participation in international curriculum networks such as the CDIO model, strong academic participation in international engineering education conferences, and the AAEE affiliation with CDIO.

The CDIO (Conceive, Design, Implement, and Operate) Initiative is an international collaboration originating around ten years ago with a collective of Universities within Sweden (Chalmers, KTH, etc), Massachusetts Institute of Technology, and the US Naval Academy. The global CDIO community [www.cdio.org] has now grown to more than 40 collaborating institutions. The CDIO concept promotes the notion that "*learning activities are crafted to support explicit pre-professional behaviour*" (Crawley et al, 2007). Much of the CDIO philosophy is in line with the expressed focus of most Australian engineering schools with the CDIO Standards and self-rating framework providing a methodology for evaluating the effectiveness of engineering program initiatives at the tertiary level.

The Australian Learning and Teaching Council (ALTC) sponsored report by Robin King, *Engineers for the Future: - Addressing the supply and quality of Australian engineering graduates for the 21st century* (2008), has made a number of recommendations to stimulate the agenda for engineering education for the next decade, and at a time when the demand for engineers significantly exceeds the supply of graduates. This paper focuses on two of the recommendations.

Raise the public perception of engineering ("…including within primary and secondary schools …")

Implement best-practice engineering education ("…define curricula more strongly around engineering problem solving, engineering application and practice, and develop the themes of design...")

These recommendations are intended to be a 'roadmap' for the next decade of development of Australia's engineering education system. A number of funded projects which are addressing, in part, these recommendations include:

Design Based Curriculum Reform within Engineering Education (Australian Learning and Teaching Council)

Australian Technology Network (ATN) Engineering in Schools (Collaboration and Structural Reform)

Implementing Engineering Experiences in the Middle School (Australian Research Council)

The National Graduate Attributes Project (Australian Learning and Teaching Council)

This paper summarises two key contributions in casting the CDIO Syllabus into the Australian engineering qualification context, and extending the CDIO self-rating framework with preparatory proficiency levels to recognise pre-tertiary engineering attribute formation.

CDIO Syllabus and Engineering Capabilities

The CDIO Syllabus is expressed hierarchically from a broad set of competency statements to finer grained syllabus topics. Each syllabus topic can be expressed in terms of the CDIO Proficiency Levels based on Bloom's Educational Objectives in the cognitive domain:- *Knowledge* (Levels 1 and 2), *Comprehension* (Level 3), *Application and Analysis* (Level 4), *Synthesis and Evaluation* (Level 5) (Crawley et al, 2007)(Bloom et al, 1956). Conceptually, this relationship is illustrated in Figure 1 (Campbell et al, 2009). Brief descriptions of the CDIO proficiency levels are given in Table 3.

The top three levels of the CDIO Syllabus can be represented in terms of *n*, *n.n* and *n.n.n*. The syllabus level *n* comprises the four broad ranging statements as shown in Figure 1. Syllabus levels *n* and *n.n* have the greatest alignment with commonly stated graduate attributes, graduate capabilities and key learning outcomes from accrediting bodies and syllabus stakeholders.

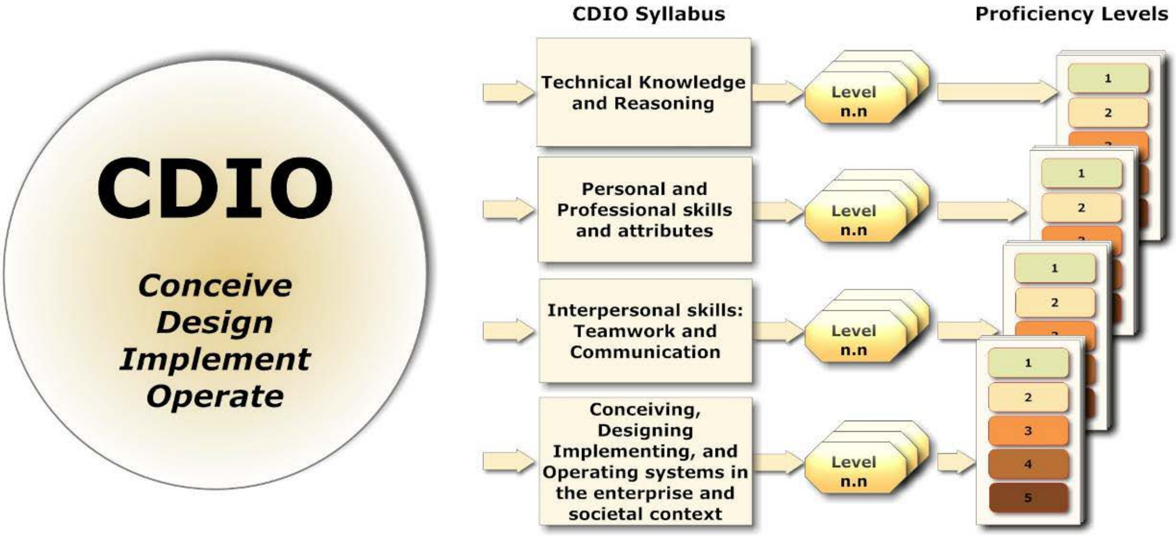

Figure 1: Conceptual view of the CDIO Syllabus with proficiency levels (Campbell et al, 2009)

CDIO Syllabus Mapping in the Australian Context

With a growing community of practice throughout the CDIO Australia and New Zealand Regional Group, and the Australasian Association for Engineering Education (AAEE) via the CDIO Special Interest Group, there is a need to map the CDIO Syllabus within the Australian context. Crawley et al (2007) have previously mapped the top level CDIO Syllabus against the ABET Graduate Outcomes. A similar process was adopted in the mapping exercise for the graduate attributes and capabilities published by Engineers Australia (EA) (Engineers Australia, 2006), the Washington Accord (WA) (an international alliance of accrediting bodies to which Engineers Australia is a signatory) (International Engineering Alliance, 2005), and the Queensland University of Technology (QUT) (to give an institutional example of graduate capability mapping) (Queensland University of Technology, 2005). These mappings are tabulated in Table 1.

Table 1: CDIO Syllabus topics mapped against graduate attributes and capabilities

	CDIO SYLLABUS TOPIC		EA GRAD. ATT.	WA GRAD. ATT.	QUT GRAD. CAP.
TECHNICAL KNOWLEDGE AND REASONING	1.1	KNOWLEDGE OF UNDERLYING SCIENCES	A	B	A
	1.2	CORE ENGINEERING FUNDAMENTAL KNOWLEDGE	A	B	A
	1.3	ADVANCED ENGINEERING FUNDAMENTAL KNOWLEDGE	C	B	A
PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES	2.1	ENGINEERING REASONING AND PROBLEM SOLVING	D	C	B
	2.2	EXPERIMENTATION AND KNOWLEDGE DISCOVERY	-	E	-
	2.3	SYSTEM THINKING	E,G	D	-
	2.4	PERSONAL SKILLS AND ATTITUDES	F,(J)	G,(M)	E,G,(D)
	2.5	PROFESSIONAL SKILLS AND ATTITUDES	I,(J)	J,(M)	F,(D)
INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION	3.1	TEAMWORK	F	G	E,G
	3.2	COMMUNICATIONS	B	H	C
	3.3	COMMUNICATIONS IN FOREIGN LANGUAGES	-	-	-
CONCEIVING, DESIGNING, IMPLEMENTING AND OPERATING SYSTEMS IN THE ENTERPRISE AND SOCIETAL CONTEXT	4.1	EXTERNAL AND SOCIETAL CONTEXT	G	I	F
	4.2	ENTERPRISE AND BUSINESS CONTEXT	-	L	-
	4.3	CONCEIVING AND ENGINEERING SYSTEMS	E,H	F,K	B,F
	4.4	DESIGNING	E,H	F,K	(A),(B)
	4.5	IMPLEMENTING	E,H	F,K	(A),(B)
	4.6	OPERATING	E,H	F,K	(A),(B)

Linkages are indicated where attributes have a “strong correlation” (eg. **A**) and those (bracketed) with a “reasonable correlation” (eg. **(J)**). This initial proposed mapping is intended for use and refinement by the growing CDIO community.

The mappings relate the CDIO syllabus topic to the relevant graduate attribute or outcomes as listed in Table 2 below.

Table 2: Summary of graduate attributes and capabilities

	EA Graduate Attributes (Engineers Australia, 2006)	WA Graduate Attributes (International Engineering Alliance, 2005)	QUT Graduate Capabilities (Queensland University of Technology, 2005)
A	Ability to apply knowledge of basic science and engineering fundamentals;	Academic Education	Knowledge and skills pertinent to a particular discipline or professional area
B	Ability to communicate effectively, not only with engineers but also with the community at large;	Knowledge of Engineering Sciences	Critical, creative and analytical thinking, and effective problem-solving
C	In-depth technical competence in at least one engineering discipline;	Problem Analysis	Effective communication in a variety of contexts and modes
D	Ability to undertake problem identification, formulation and solution;	Design/ development of solutions	The capacity for life-long learning
E	Ability to utilise a systems approach to design and operational performance;	Investigation	The ability to work independently and collaboratively
F	Ability to function effectively as an individual and in multi-disciplinary and multi-cultural teams, with the capacity to be a leader or manager as well as an effective team member;	Modern Tool Usage	Social and ethical responsibility and an understanding of indigenous and international perspectives
G	Understanding of the social, cultural, global and environmental responsibilities of the professional engineer, and the need for sustainable development;	Individual and Team work	Characteristics of self-reliance and leadership
H	Understanding of the principles of sustainable design and development;	Communication	
I	Understanding of professional and ethical responsibilities and commitment to them; and	The Engineer and Society	
J	Expectation of the need to undertake lifelong learning, and capacity to do so.	Ethics	
K		Environment and Sustainability	
L		Project Management and Finance	
M		Life long learning	

Extended CDIO Preparatory Capabilities

There is evidence that many graduate attributes can develop, at least to a limited extent, through studies prior to tertiary engineering degree programs (Dawes et al, 2008). Feedback from industry representatives on the Queensland Studies Authority (QSA) senior secondary school Engineering Technology curriculum has been positive in terms of the rigour in the curriculum and identifies the major strength as developing problem solving skills and producing tangible outcomes (QSA, 2004).

To read the learning objectives, it is not immediately clear that they are cast within the context of a senior secondary school syllabus (QSA, 2004). Indeed, one could have difficulty discerning these from professional graduate capabilities. This context may be defined, relative to the tertiary level proficiencies, as one:-

That is highly controlled in a highly supervised environment

That has limited scope and context of topics, and learning activities

That has outcomes which are generally aligned with graduate attributes, however the levels of proficiency are somewhat limited in comparison

The CDIO framework bases the levels of proficiencies on Bloom’s Educational Objectives (in the cognitive domain). This framework has been extended to include sub-levels, or *preparatory levels of proficiencies*. This is done with the same sets of verbs, however within the preparatory context characterised in the previous section. The established CDIO proficiency levels, linked to Bloom’s Educational Objectives is tabulated in Table 3 and extended to include the proposed preparatory sub-levels (Campbell et al, 2009). This process will inform application to other preparatory pathways to undergraduate engineering programs.

Table 3: CDIO levels of proficiencies expanded to include preparatory proficiencies.

Bloom's Educational	CDIO Proficiency	Preparatory Proficiency Extension
Knowledge	To have experience or been expose to … To be able to participate in and contribute	**Prep1** To have elementary knowledge and **Prep2** To be able to participate in and
Comprehension	To be able to understand and explain …	**Prep3** To be able to understand and explain
Application **Analysis**	To be skilled in the practice or implementation of …	**Prep4** To have preparatory skills in the practice and implementation of …
Synthesis **Evaluation**	To be able to lead or innovate.	**Prep5** Beyond the scope of preparatory proficiency.

Graduate Attribute Mapping Tool

A demonstrator graduate attribute mapping tool was created in Microsoft Excel (snapshot shown in **Figure 2**). The tool embeds the mapping relationships developed for Table 1 and includes the extended proficiency levels summarised in Table 3. For each unit of learning (could be a unit, course, major, module, program etc), an evaluation is made against learning outcomes, CDIO Syllabus or graduate attribute, in terms of assumed proficiency at entry, teaching, learning activities, assessment, and attainment on exit. One objective in the mapping process is to ensure the coherent and progressive development of graduate attributes through the unit of learning. Inconsistencies and misalignments can be identified through examination of the summarised data.

The tool was created as a demonstrator and a mechanism around which to design curriculum, and to elicit information from unit descriptions, unit leadership and unit teaching teams to explore the learning outcome relationships with broader sets of institutional graduate attributes.

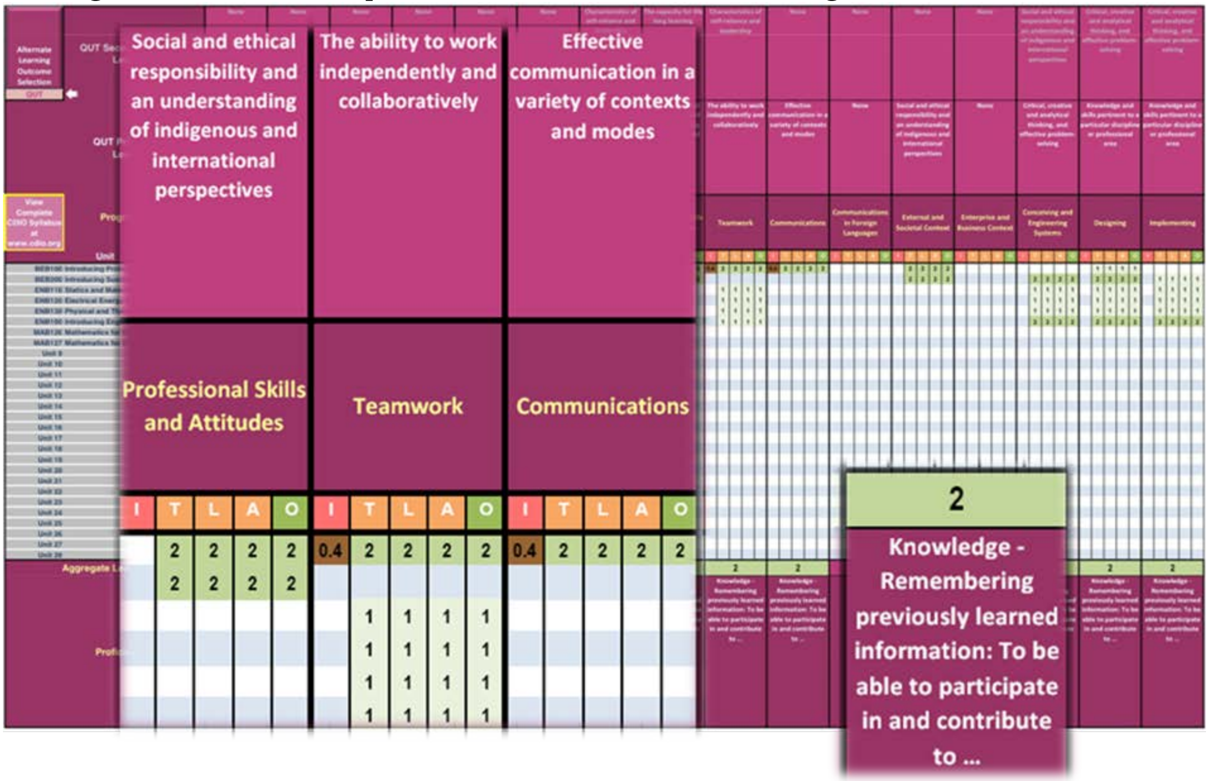

Figure 2: Demonstrator graduate attribute mapping tool

Given the multi-faceted view of graduate attributes from students centred graduate attribute formation, professional accreditation processes, educational researchers, learning experts, curriculum designers, and the internationalisation and mobility agenda, the vision is to move toward an integrated curriculum information system as modelled in Figure 3.

Conclusion

The CDIO Syllabus mapping and extended proficiency framework presented in this paper provides a transparent connection between engineering education communities within Australia and the CDIO global community of practice. It is the intention that a more fluid pathway now exists for sharing of ideas, processes, resources and initiatives in global efforts of engineering curriculum reform. Through these contributions, a further mechanism now exists for globalisation of the curriculum, and to foster student mobility.

The framework is consistent with conventional application to undergraduate programs and professional practice, but adapted for the preparatory context. Through this extended CDIO framework, students and faculty have greater awareness and access to tools to promote (i) student engagement in their own graduate capability development, (ii) faculty engagement in course and program design, through greater transparency and utility of the continuum of graduate capability development with associate levels of proficiency, and the context in which they exist in terms of pre-tertiary engineering studies; and (iii) course maintenance and quality audit methodology for the purpose of continuous improvement processes and program accreditation.

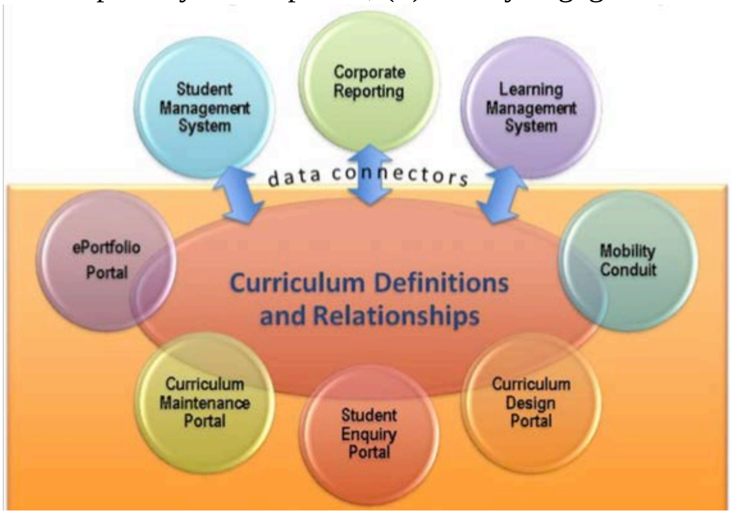

Figure 3: An Integrated Curriculum Information

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