Graduate Attribute Mapping With the Extended CDIO Framework

Duncan Campbell
Les Dawes
Hilary Beck
Sam Wallace
Marian Boman
Queensland University of Technology, Brisbane, Australia
da.campbell@qut.edu.au

Carl Reidsema
University of New South Wales, Sydney, Australia

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.

1. **Raise the public perception of engineering** ("…including within primary and secondary schools …")
2. **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:

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

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

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

(iv) **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.

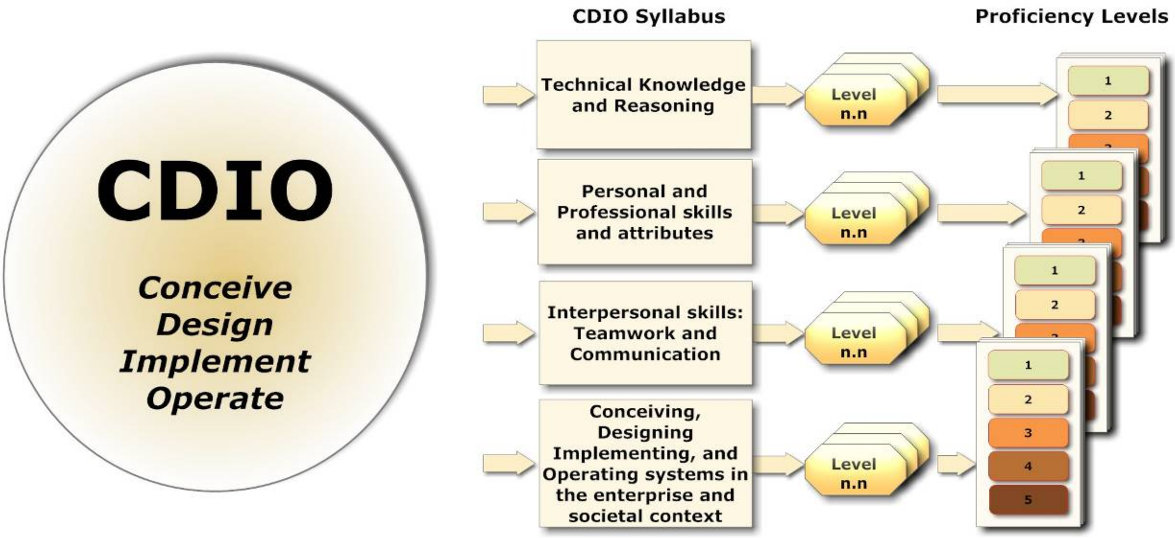

Figure 1: Conceptual view of the CDIO Syllabus with proficiency levels (Campbell et al, 2009)

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:-

1. That is highly controlled in a highly supervised environment
2. That has limited scope and context of topics, and learning activities
3. 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	**1** To have experience or been expose to **2** To be able to participate in and	**Prep1** To have elementary knowledge and **Prep2** To be able to participate in and
Comprehension	**3** To be able to understand and explain	**Prep3** To be able to understand and explain
Application **Analysis**	**4** To be skilled in the practice or implementation of …	**Prep4** To have preparatory skills in the practice and implementation of …
Synthesis **Evaluation**	**5** 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.

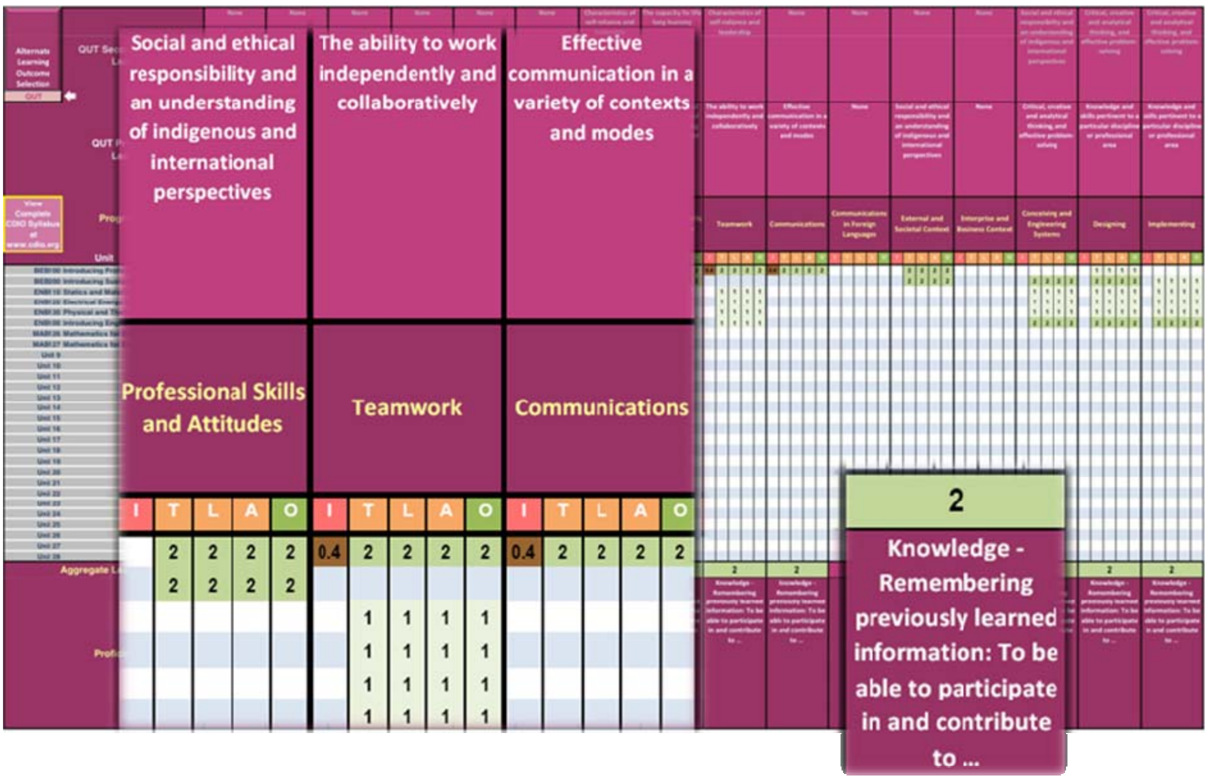

Figure 2: Demonstrator graduate attribute mapping tool

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.

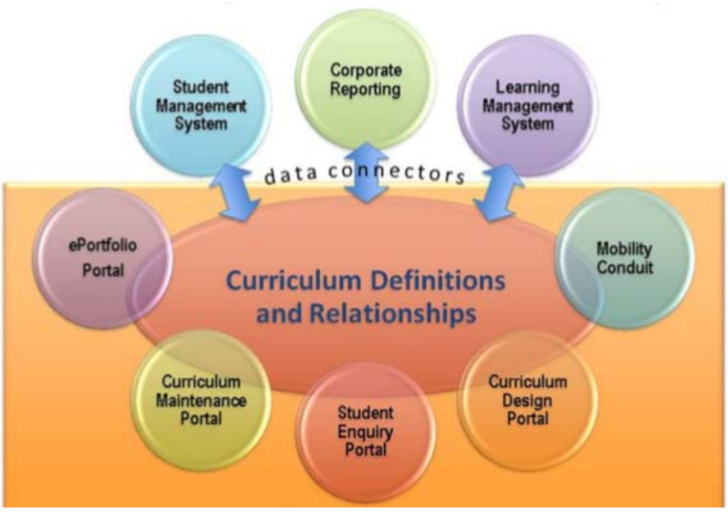

Figure 3: An Integrated Curriculum Information Model

References

Barrie, S., Hughes, C., Smith, C., Thomson, K., “The National GAP Issues Papers”, The National Graduate Attributes Project, 2009.

Bloom, B., Englehatt, M., Furst, E., Hill, W., and Krathwohl, D., Taxonomy of Educational Objectives: Handbook 1 – Cognitive Domain, McKay, New York, 1956.

Campbell, D., Dawes, L., Beck, H., Wallace, S., Dansie, B., Reidsema, C., (2009) *An extended CDIO syllabus framework with preparatory engineering proficiencies.* In: Proc. 5th International CDIO Conference, 7-10 June 2009, Singapore Polytechnic, Singapore.

Crawley, E., Malmqvist, J., Ostlund, S., Brodeur, D., “Rethinking Engineering Education – The CDIO Approach”, Springer, 2007.

Dawes, L., Campbell, D., Dansie, B., Beck., H., and Wallace, S., "Inspiring secondary and tertiary students through applied electronics”, Proc. 19th Annual AAEE Conference, Yeppoon, Australia, 2008

Engineering Technology Senior Syllabus, The State of Queensland (Queensland Studies Authority), 2004.

Engineers Australia Policy on Accreditation of Professional Engineering Programs, Engineers Australia, 2006

Felder, R. and Brent, R., 2003. Designing and Teaching courses to satisfy the ABET Engineering criteria, Journal of Engineering Education, 92(1): 7-25.

Graduate Attributes and Professional Competencies, International Engineering Alliance, 2005.

Graduate Capabilities, Manual of Policies and Procedures, Queensland University of Technology, 2005.

King, R., Addressing the Supply and Quality of Engineering Graduates for the New Century, March 2008.

Rover, D., 2008. Attention Engineering Educators, Journal of Engineering Education, 97(4): 531-534.