A comparison and evaluation of the CDIO reference syllabus against the Engineers Australia competency standards and the development of a new compact framework.

Alcion Benedict Popp
Sydney University, Sydney, Australia
alci@eng.usyd.edu.au

David C. Levy
Sydney University, Sydney, Australia
dlevy@ee.usyd.edu.au

Abstract*: This paper will compare and evaluate the CDIO reference syllabus, the Engineers Australia competency standards and Electrical Engineering Program at the University of Sydney. Gaps and conflicts will be identified and modifications suggested to the CDIO Syllabus and to the Competency standards through the development of a new framework that embodies the concepts from CDIO and Engineers Australia. The Electrical Engineering program will be evaluated against this new framework, a gap analysis will be carried out and changes to the program identified.*

Introduction

Engineering education before World War 2 and leading into the early 1950s emphasised engineering practice. This was because the engineering departments themselves were at the centre of engineering practice (Crawley *et al*, 2007). After this period, engineering education began to slowly transition to a more scientific approach, as new academics were technical experts specializing in fairly narrow fields and geared towards scientific research rather than solvers of open-ended problems (Gustafsson, 2004). This trend continued and peaked in the 1980s. In the 1990s, with the onset of industry pressure for change, the pedagogical approach began to shift back towards design and synthesis rather than problem analysis. This gradually resulted in a more balanced implementation of fundamentals concomitant to the personal, interpersonal and system building skills needed in modern day practice.

This need for change led to the development of many revisions to the national frameworks and standards; in Australia the Engineers Australia National Generic Competency Standards (NGCS) (Bradley, 2006); in the United States, the Accreditation Board for Engineering and Technology (ABET) EC2000 criteria (ABET, 2008); in the UK the Accreditation Board of Engineers featuring the Engineering Criteria UK (ECUK) (EAB, 2008). There have also been many other initiatives from various universities or groups of universities. The CDIO syllabus (Conceiving - Designing - Implementing - Operating) (Bankel *et al*, 2003) is an example of an initiative by multiple universities, including KTH, Linköping and Chalmers in Sweden and MIT in the USA with the overarching aim of further reform in engineering education. The syllabus represents a set of learning objectives for undergraduate engineering education, coded with specific proficiencies related to contemporary engineering knowledge, skills and attitudes, set in the context of real-world systems and products.

Based on these standards and others alike, many universities have revamped their curricula to implement education in generic skills. One example is the University of Queensland's (UQ) Project Centred Curriculum (PCC) with the simulation of professional practice through project centred subjects in each semester (Crosthwaite *et al*, 2006). Other examples are more extreme, such as Aalborg University and McMaster University where the entire curriculum is project based.
This paper presents how the School of Electrical Engineering and Information Engineering at the University of Sydney has developed a new generic framework from the CDIO syllabus and the

Engineers Australia NGCS, for closer alignment with the needs of the Australian higher education system. This new generic framework, named the 'Unified Code', has been developed from merging the CDIO syllabus and the Engineers Australia NGCS frameworks. This has been done in a two step process, initially mapping the two frameworks against each other, followed by the translation of this map into a new framework using Bloom's taxonomical domains as guiding reference. Following this process, a mapping tool has been developed using a customized Excel workbook to map the program streams from Electrical Engineering against the new framework. A gap analysis has been conducted using this tool and the information has been used to improve the streams and their coverage of the framework.

Development of a New Framework (Unified Code)

Inputs

The CDIO syllabus was not developed in isolation, but was based on the ABET EC2000 criteria and Boeing's 'Desired Attributes of a Graduating Engineer' (Bankel *et al*, 2003). This framework was subsequently extensively validated both in the United States and in Sweden with the help of faculty, alumni and industry and domain experts.

The Engineers Australia NGCS is a set of standards developed by the Engineers Australia Accreditation Board as part of an accreditation management system for education programs at the level of professional engineer. The standards feature three main domains of competency, namely;

- Knowledge Base, which relates to all the fundamental and technical knowledge;
- Engineering Ability, which addresses problem solving techniques, responsibilities of engineers, project design issues and business principles; and
- Professional Attitudes, which includes elements of effective communication, team work, ethical responsibilities and other professional attitudes.

The sub-domains of the three main domains are similar in content and meaning to the CDIO syllabus, but there are also instances where the two differ. This was the catalyst for the initial mapping of the two frameworks.

Process (mapping the two frameworks)

The mapping process began with a close overview of the two generic frameworks, at their finest level of detail. This exercise was part of an effort to establish which framework to use as the driver of the mapping process. The CDIO framework offers four levels of detail, while the Engineers Australia NGCS offers three. The CDIO syllabus was therefore used as the reference, as its higher level of detail would most likely cover all of the third level items in Engineers Australia NGCS.

Mapping

The CDIO and NGCS frameworks are shown in the spreadsheet in Figure 1 below, which has three columns for each, showing three levels of detail. Since the CDIO syllabus was being used as the reference, its top three levels of detail were inserted in the order presented in the CDIO Syllabus. When comparing a third level item in the CDIO syllabus, say 2.1.1 'Problem Identification and Formulation', an attempt was made to find third level items from EA standards to match.

When a match was found, the respective third level item from the Engineers Australia NGCS was inserted along the same row but within its own set of columns to keep both standards distinct but aligned. Multiple matches were allowed from the EA standards. For example, item 2.1.1 from CDIO framework has two matches from the EA standards (PE 2.1.a and PE 2.4.c). The strength of the match was also considered; strong matches were drawn in black, while weak matches in grey.

The second level did not involve a direct comparison to the CDIO standards, but is representative of an aggregation of the third level matches. Where third level items had weak relationships, these have not been aggregated upwards. For example, if 'PE 2.1.a' and 'PE 2.1.d' from the Engineers Australia NGCS matched to third level CDIO items, then the second level mapping of the two frameworks would be indicative of this.

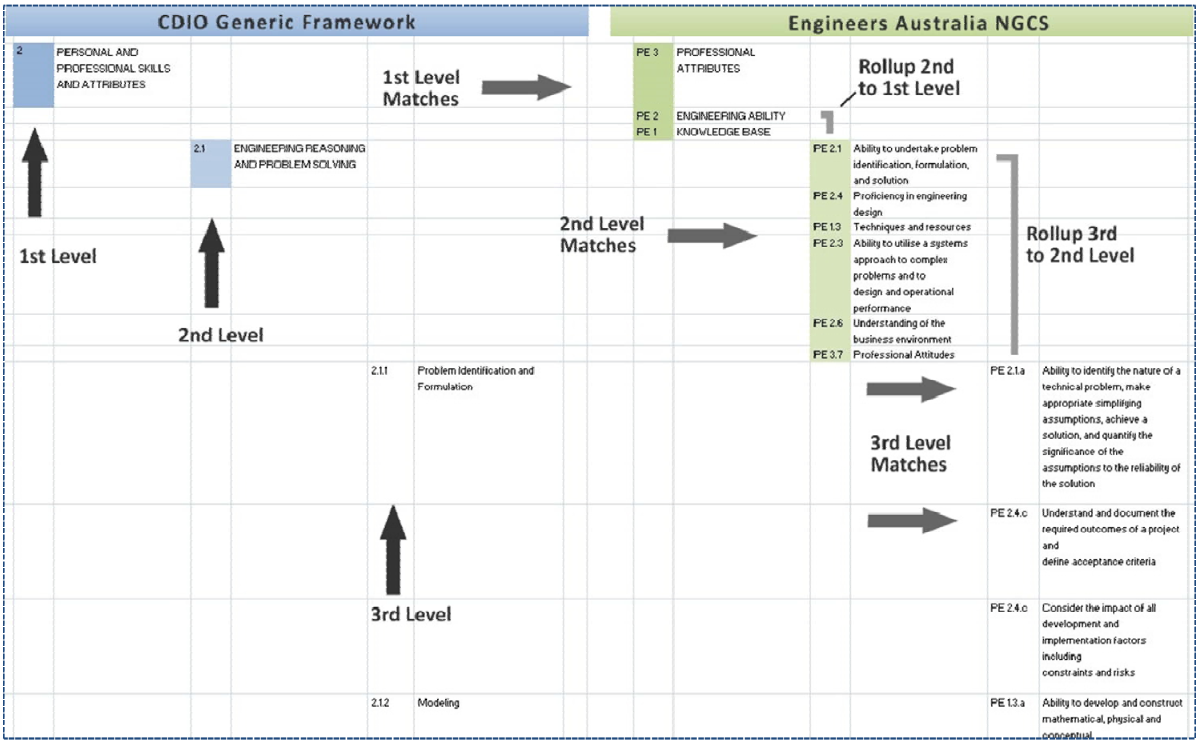

Figure 1: CDIO Syllabus vs. Engineers Australia NGCS mapping setup

Output (creating the new framework)

To make the above mapping exercise useful in the context of benchmarking and hence mapping of other frameworks or curricula, it was recognized that the mapped information needed to be transformed into one template or reference and could not be efficiently used in its current state as shown in Figure 1, as it would mean that users would need to map against two frameworks concurrently, a difficult and resource intensive exercise. It was therefore decided to use the mapping information to output a new generic framework termed the 'Unified Code', which could embody the information from both frameworks in one compact package.

Taxonomical domain classification was performed on each pair of mapped items using Bloom's taxonomy of educational objectives (Bloom, 1956), to objectively determine the proficiency level of each item in a pair. This process is similar to what had been done at the inception and development of the CDIO syllabus where the knowledge, skills and attitudes had been turned into goals by determining the required proficiency and correlating to specific taxonomies (Bankel *et al*, 2003).

Using these cognitive, affective or psychomotor domain classifications, each item pair was reduced to one item at the respective hierarchical level. Generally speaking the higher classification was retained wherever possible, so if one item was classified as 'application' and another as 'analysis', then 'analysis' was transferred as this is a higher cognitive skill level. A certain amount of reduction and re-arrangement of the various items was also possible in the development of the 'Unified Code', as some items were seen to clearly overlap both taxonomically and in scope. Due to space limitations, the complete map and the 'Unified Code' are not shown here, but are available from the authors.

Additions, Modifications & Major Changes

Table 1 represents a high level summary (headings only) of new or highly modified items in the 'Unified Code', which did not exist in either of the two base frameworks (CDIO and NGCS). These items are part of our contribution towards improving the usefulness of the 'Unified Code' in the context of engineering education in Australia. A summative description for each set of correlated items, including the benefits of the additions and modifications has also been included. We anticipate that these additions and modifications will lead to further debate and possible merger into the CDIO syllabus and Engineers Australia NGCS source documents.

Table 1: 'Unified Code' new content and major modifications.

New or Modified Item	Modifications / Benefits
U 3.3 Language Protocol U 3.3.1 World English Standard U 3.3.2 Foreign Languages	Greater focus to the skill and proficiencies developed in adopting a language protocol. Emphasis on the benefits from using foreign languages transparently in communication. Added a description for each of the 3rd level items.
U 3.4 Leadership Elements U 3.4.1 Situation Analysis & Leadership Style Selection. U 3.4.2 Leadership Strategy & Demeanour. U 3.4.3 Leadership Function. U 3.4.3 Espousal.	The re-work of these items has produced a set of 3rd level items which have a tighter scope, with an increased reference to leadership and a reduced reference to communication. The items have an improved flow through them, as a result of their complementary nature. Users may find this new set easier to follow as a clear and structured approach. Mapping against these items may also be facilitated as a result of the distinct scope of each item.
U 4.2.3 Management Hierarchy & Function	The original item was described in terms that were difficult to quantify such as 'working successfully'. The proficiency embodied by the new reworked item is more transparent to potential users. The cognitive domain classification and the focus level of the item have been changed. The focus has been moved away from describing individual roles, responsibilities and functions in organizations, to a higher level overview with interwoven specific examples. The cognitive level has been upgraded from 'describing' to 'evaluating' the higher level overview.
U 4.4.2 Design Phases - Preliminary Analysis. U 4.4.3 Design Phases - Preliminary Research. U 4.4.4 Design Phases - Detailed Solution Design.	Three new items have been developed from the one item. The new items are easier to map against, as each item is specific to a certain activity. Each item also exposes the required proficiency for that activity. The items have a clear logical flow between each other, which make it easier for users to select the correct item when mapping or to implement the item during curriculum design. The items are implemented by using a stem and range modifier, similar to the approach taken by the International Engineering Alliance in their latest document on the Washington, Sydney and Dublin Accords (International Engineering Alliance, 2009).
U 4.6.1 Defining the Operational Approach	The new item introduces the correlation between the implementation of deliverables and the operational metrics involved, taking a holistic approach, which could include the feedback cycle emphasized by 'PE 2.3.h' from Engineers Australia NGCS. The new item emphasizes that the deliverables should be influenced to some extent by the desired configuration and metrics of the operational approach.
U 4.6.2 Operational Training	Greater emphasis given on the methods of training and the benefits of training to the trainees and the organization.
U 4.6.3 System, Process or Product Life Cycle Scheduling.	New item described in clearer terms, referring to 'life cycle scheduling' as the main aim. Specific reference to marginal and operational cost and its relationship to reliability. Included the social and environmental aspects of life cycle scheduling for a more holistic approach. Developed the compromise between performance, risk of failure and the respective cost of the chosen risk profile. This is included as an asset management concept.
U 4.7.1 Business Structure & Setup.	Developed a description of the process for business structure selection and setup, giving better guidance to potential users of the item. The item is complementary with U 4.7.2
U 4.7.2 Business Capitalization.	Developed a description of the method of capitalization of companies and businesses using the various business models as the main drivers. The link between capitalization and the respective business models promotes the logic of the item. The proficiencies and abilities required for conformance to the item are clearly stated. The item is complementary with U 4.7.1
U 4.7.3 Market Identification & Strategy.	Described the techniques of market segmentation, making the item easier to implement in curriculum design. Defined the proficiency on the basis of Bloom's taxonomical domains. This item is complementary to U 4.7.5

U 4.7.4 Competitor Identification & Strategy.	This item addresses the specific skills and techniques of identifying competitors and can therefore be used as a guide in curriculum design. This item provides a business related extension to both frameworks, as this is not addressed in either. This item is complementary to U 4.7.5
U 4.7.5 Product Implementation & Positioning Strategy.	Described a clearer way of market penetration, complementary to items U 4.7.3 and U 4.7.4 Used examples as the drivers of the description, making it easier to implement from a user's perspective.
U 4.7.6 Identifying IP. U 4.7.7 Strategy in Protecting IP.	Separated the intellectual property (IP) issue in two stages, namely; the ability to recognize and evaluate IP and secondly, the ability to undertake protectionist measures for safeguarding the IP. The cognitive classification in identifying IP is set to 'evaluate', as judgement is required in order to work with intellectual property. Protecting IP requires the user to only have comprehension of the methodology employed. This is disconnected from an understanding of the IP. Therefore the cognitive skill level of 'identify' has been used which translates to comprehension. The two complementary items are easier to map against as their scope is clearly separate. The two items are also more useful in curriculum design.
U 4.8.7 Innovation & Applicability.	Developed a clear description of innovation and its intrinsic dependence on applicability. The distinction from invention has also been made to reduce scope overlap. This item is complementary to U 4.8.8
U 4.8.8 Invention & Originality.	Described invention in clearer terms and with examples to better qualify its existence. This item is complementary to U 4.8.7

Electrical Engineering vs. Unified Code (gap analysis)

Process

The mapping process of Electrical Engineering streams against the Unified Code has been made possible through a graphical tool developed within an Excel workbook. The tool maps an entire stream against the framework to reveal the degree of coverage of various items in the framework by the particular stream and the selected electives. Appropriate interfaces are provided in the workbook for the user to configure the stream in terms of electives and the gap-analysis method to be used (i.e. 'relative' or 'global').

The data used for the mapping are the learning outcomes assigned by subject coordinators to each subject, drawn directly from the Faculty of Engineering's Units of Study (UoS) database, which is frequently updated. These learning outcomes have been aligned with the respective items in the generic framework, checked by academics and then aggregated across the entirety of subjects selected for mapping within a particular program stream.

Output

On average most of the streams scored well in fundamental and core knowledge, engineering reasoning, problem solving and experimentation skills and abilities. A lower but adequate coverage was observed across most of the other generic items such as personal attitudes, teamwork elements, communication elements, conceiving, designing and implementing skills and abilities.

A shortage was generally seen in items such as innovative thinking, leadership and responsibility, corporate and enterprise knowledge, foreign language knowledge, operational, management and inventive skills and abilities. The detailed gap-analysis output from the developed application can be provided by the authors on request. A full demonstration of the application's capabilities and flexibility with respect to elective subjects can also be arranged.

Outcomes

The output from the Unified Code mapping has helped to better gauge the shortcomings of programs offered by the School of Electrical and Information Engineering, with respect to providing an all inclusive education to students. The low performance areas are now being addressed in school meetings and by academics involved with program review, in order to improve the program. The authors have also begun the mapping process on the Aerospace, Mechanical and Mechatronic Engineering program, the results of which are hoped to be the subject of future papers in the area.

Results

The structured comparison between the CDIO syllabus and Engineers Australia NGCS has revealed commonalities and gaps between the two frameworks. Overall the commonalities were strong, and many items from one framework mapped against multiple items in the other. This is partly due to a certain degree of scope overlap between various items within the same framework. Gaps between the two frameworks have been recorded and addressed through the development of a new framework, the 'Unified Code' which embodies concepts from both frameworks. Additions and modifications have been made to many elements in the creation of the new generic framework to ensure consistency and flow. These additions and modifications can in time be presented and perhaps propagated back to the original frameworks.

The new 'Unified Code' is a more complete generic framework which inherits the extensive work and validation conducted by the CDIO initiative and extends it with reference to the Australian standards, for a better fit in future mappings against engineering curriculums in Australian universities.

The gap analysis between the Unified Code and the various program streams in Electrical Engineering has revealed the strong and weak points for each stream, as well as the common points across all of the streams in the Electrical Engineering program. The mapping approach and gap analysis tools developed by the authors will allow academics to take an objective and aggregate view of the coverage provided in each stream with respect to a specific reference framework. This will help to rebuild and improve curricula across engineering programs in a more efficient and organized way.

References

ABET. (2008, November). *Criteria for Accrediting Engineering Programs.* Retrieved June 21, 2009, from ABET: http://www.abet.org/

Bankel, J., Berggren, K.-F., Blom, K., Crawley, E. F., Wiklund, I., & Östlund, S. (2003). The CDIO Syllabus: A comparative study of expected student proficiency. *European Journal of Engineering Education , 28* (3).

Bloom, B. S. (1956). *Taxonomy of Educational Objectives, Handbook I: The Cognitive Domain.* New York: David McKay Co Inc. .

Bradley, A. (2006, July). *Engineers Australia National Generic Competency Standards – Stage 1 Competency Standard for Professional Engineers.* Retrieved June 21, 2009, from Engineers Australia: http://www.engineersaustralia.org.au/

Crawley, E., Malmqvist, J., Ostlund, S., & Brodeur, D. (2007). *Rethinking Engineering Education: The CDIO approach.* Springer.

Crosthwaite, C., Cameron, I., Lant, P., & Litster, J. (2006). Balancing Curriculum Processes and Content in a Project Centred Curriculum: In pursuit of graduate attributes. *Education for Chemical Engineers , 1*, 39-48.

EAB. (2008). *The Accreditation of Higher Engineering Programs - UK standard for Professional Engineering Competence.* Retrieved July 7, 2009, from EAB - The Engineering Accreditation Board: http://www.engab.org.uk/

Gustafsson, G. (2004). Experiences from the transformation of an engineering education introductory project design course into a project design-build-test course. *NordDesign 2004 – Product Design in Changing Environment.* Tampere, Finland.

International Engineering Alliance. (2009, June 18). *International Engineering Alliance.* Retrieved July 19, 2009, from International Engineering Agreements: http://www.washingtonaccord.org/IEA-Grad-Attr-Prof-Competencies-v2.pdf

Copyright © 2009 Remains the property of the author(s). The author(s) assign to AaeE and educational non-profit institutions a non-exclusive licence to use this document for personal use and in courses of instruction provided that the article is used in full and this copyright statement is reproduced. The author(s) also grant a non-exclusive licence to AaeE to publish this document in full on the World Wide Web (prime sites and mirrors) on electronic storage and in printed form within the AaeE 2009 conference proceedings. Any other usage is prohibited without the express permission of the author(s).