Engineering curriculum structure and mapping: accreditation and beyond

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Structured abstract

CONTEXT

In most Australian engineering schools and faculties, engineering programs are not ordered and deliberately structured entities. The University of Tasmania offers undergraduate engineering in two locations, Hobart's School of Engineering offers eight specialisations and Launceston's National Centre for Maritime Engineering and Hydrodynamics (NCMEH) at The Australian Maritime College (AMC) offers three specialisations. Preparing for EA accreditation, the Hobart and Launceston groups co-operated to make sense of four seemingly disparate elements of engineering curriculum: the TLOs for Engineering, unit learning outcomes (ULOs), unit assessment tasks and the EA's Stage 1 Competency Standard. In this paper we describe processes for redeveloping, linkage and auditing of three curriculum elements to build a more cohesive, manageable curriculum structure to meet EA, QA and student expectations.

PURPOSE OR GOAL

The authors sought to make sense of various elements of curriculum, curriculum administration and quality assurance processes with a view to demonstrating how engineering programs can better be audited for accreditation, and curriculum structure better managed.

APPROACH

Academics, students and industry partners were consulted. A range of methods was used including: stakeholder consultation, co-operative audit and matrix building, and structured student engagement.

ACTUAL OR ANTICIPATED OUTCOMES

The key outcome is greater clarity on what *program-level* curriculum structure might mean and how such a structure might be decided and maintained.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Engineering curriculum is not entirely unwieldy, but it is impractical and inefficient to attempt rigid control over all aspects of curriculum. The mechanisms presented here offer curriculum managers the option of identifying those parts of curriculum structure which might best be maintained and managed centrally, and those parts of the curriculum which are best left to the devices and creativity of unit co-ordinators.

KEYWORDS

Accreditation, threshold learning outcomes, Stage 1 Competency Standards, curriculum mapping

Introduction

Preparing for Engineers Australia (EA) accreditation offers engineering schools and faculties a choice: present the current curriculum in the best possible light, or use preparation for accreditation as a catalyst for curriculum change? The former, simply mapping what is currently on offer, is usually a lower risk, lower effort option and one which may appeal in a change-weary, budget-constrained, research-focused faculty (and sector). In most Australian schools and faculties, engineering programs are not ordered and deliberately structured entities. This is because an engineering curriculum grows like a climbing plant, and often vigorously resists efforts at pruning or redirecting. The current era in Australian engineering education is one of threshold learning outcomes (TLOs), Tertiary Education Quality Standards Agency (TEQSA) audits and an apparent desire by EA for explicit program objectives and related, deliberate curriculum structure. In this new era, it appears that engineering curricula should be engineered!

The Stage 1 Competency Standard (Engineers Australia, 2011) often drives the accreditation process and requires each engineering school to demonstrate 16 elements of competency are achieved as program outcomes. In parallel, each program has its own statement of program learning outcomes (PLOs) and each university has its own list of graduate attributes (GAs). In addition EA has stated that a professional engineering program is expected to include specified proportions of the Total Learning Experience (Engineers Australia, 2008). The Higher Education Standards Panel (HESP) has not yet mandated the use of the TLOs, but rather has drafted a standard statement that requires each university to have demonstrated that they have considered such ‘reference points’ both here and abroad. In this context, the EA Stage 1 Elements of Competency are also reference points to be considered. The actions of HESP are moving towards a formal way of requiring universities to demonstrate best practice both nationally and internationally.

This paper presents a logical framework that connects and quantifies the various components that structure an engineering degree.

Contexts

The inter-relationship between curriculum elements described in this paper comes from ideas and outcomes developed by University of Tasmania (UTAS) staff and one of the ALTC Discipline Scholars for Engineering and ICT, around the impending EA accreditation of UTAS’s two engineering groups. UTAS offers undergraduate engineering in two locations: Hobart's School of Engineering (SoE) and Launceston's NCMEH at AMC.

The SoE in Hobart offers eight specialisations, civil, geotechnical, mechanical, mechatronic, power electrical, electronics and communications, computer systems and biomedical. It is a small School consisting of approximately 16 academics and 350 students. A unique feature of the program is the common first 3 semesters where participation in a range of units develops students’ learning across the traditional disciplines of civil, mechanical and electrical engineering before they decide on their pathway. Sufficient discipline specific learning outcomes are achieved later in the program.

The NCMEH offers three specialisations, Marine and Offshore Engineering, Naval Architecture, and Ocean Engineering. NCMEH is a small School consisting of 16 academic staff and 390 students. As with the SoE’s program, the first 3 semesters of the AMC engineering program consist of common units across engineering specialisations.

Students enrolled in the SoE BE program may choose to complete the first year at NCMEH in Launceston, as both degree programs feature a similar first year. SoE students also have the option to transfer to NCMEH after first year. The close alignment of first year units is confirmed through regular benchmarking activities between the SoE and NCMEH programs. Students may also transfer between degree program specialisations at completion of first year.

The ideas presented in this paper are a ‘work in progress’ which shows the emerging thinking from the two UTAS groups on preparation for EA accreditation and how this may lead to clearer means of representing, auditing and managing engineering curriculum. Some, but not all of the ideas presented in this paper have been or will be implemented by the UTAS engineering groups. Some will never make it off the drawing board. By publishing these ideas, however, other engineering educators may adapt and implement them elsewhere, when the mood or context is ripe for change.

Curriculum structure elements

This paper describes several curriculum structure elements which are either referred to in EA documentation or appear central to coming university-level and national quality assurance processes. We attempt to show how these elements can fit together to build a cohesive, manageable framework for quality assurance and reporting in engineering education. These elements are also presented as candidates to streamline and improve the management of engineering curriculum, by delimiting that which needs to be centrally maintained, from that which should be the province of individual unit co-ordinators and lecturers to develop and deliver autonomously. We describe:

- Development of Program Level Objectives (PLO) written in the form of the national Threshold Learning Outcomes (TLOs). The TLOs have previously been mapped to the EA Stage 1 Competency Standard and that mapping forms a bridge from the PLOs to the EA Stage 1 Standard.
- Redevelopment of Unit Level Objectives (ULO) written in the form of the TLOs, building toward each discipline-specific PLO, and explicitly linked to unit assessment tasks.
- Calculating proportions of Total Learning Experience from EA Stage 1 Competencies
- Mapping of unit assessment tasks to the EA Stage 1 Competency Standard. This mapping provides another link between the ULOs, PLOs and EA Stage 1 Competency Standard.

The relationship between some of these elements is shown in Figure 1.

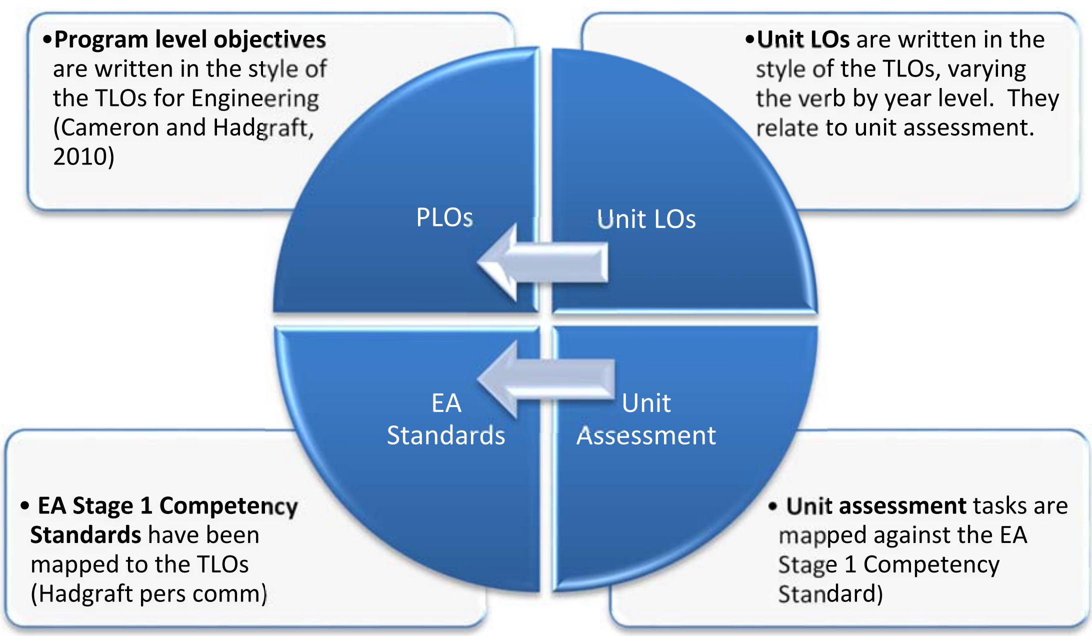

Figure 1 – Relating four elements of engineering curriculum to create curriculum structure

The threshold learning outcomes (TLOs)

Table 1 - The Engineering and ICT threshold learning outcomes

Learning Outcome Area	Rationale
Needs, Context and Systems	Graduates must be able to recognise, understand and interpret socio-technical, economic and sustainability needs within the context of engineering and ICT challenges. Systems thinking enables graduates to represent the individual components, interactions, risks and functionality of a complex system within its environment.
Problem solving and Design	Engineering and ICT professional practice focuses on problem solving and design, whereby artefacts are conceived, created, modified, maintained and retired (lifecycle assessment). Graduates must have capabilities to apply theory and norms of practice to efficient, effective and sustainable problem solution.
Abstraction and Modelling	Graduates must be able to model the structure and behaviour of real or virtual systems, components and processes. Decision making is informed by these processes of abstraction, modelling, simulation and visualisation, underpinned by mathematics as well as basic and discipline sciences.
Coordination and Communication	Engineering and ICT practice involves the coordination of a range of disciplinary and interdisciplinary activities as well as the exercise of effective communication to arrive at problem and design solutions, usually in team contexts.
Self Management	Graduates must have capabilities for self-organisation, self-review, personal development and lifelong learning.

The threshold learning outcomes (Cameron and Hadgraft, 2010) were developed within the ALTC's Learning and Teaching Academic Standards Project and are reproduced below for easy reference. The guiding philosophy of these TLOs was to capture a sense of engineering practice, which begins with a need to be addressed, relies on a systematic problem solving process (e.g. the design process, which has been formalised as systems engineering), which relies on abstract modelling of the proposed system. Engineering is a team activity, so coordination and communication are vital and each team member needs to be a reflective practitioner, able to mange their own processes and personal development.

PLOs in the style of TLOs

UTAS policy is that each unit outline should contain program learning objectives (PLOs). PLOs for the SoE were roughly drafted in the form of the TLOs and then taken through an extensive consultation process, via discipline leaders from within the SoE. Discipline leaders consulted staff, students and industry contacts for input and feedback on the PLOs as representing what was genuinely observed in UTAS SoE graduates. Final draft PLOs were reviewed by the Head of School and the SoE's industry advisory group before being formally adopted by the SoE and publicly displayed. Alternate processes for consulting stakeholders on the requisite program objectives have been described in the literature (Goldfinch et al., 2007; Patil et al., 2008). As an example, the PLOs for Geotechnical Engineering are reproduced below. As is apparent, the particular strengths of this specialisation at UTAS are reflected in the wording of the PLO.

Geotechnical Engineering

UTAS Geotechnical Engineering graduates are prepared to:

1. Select and use appropriate means of communication to consult and negotiate with stakeholders and colleagues to craft engineered solutions that are environmentally sound, economically feasible, safe, and appropriate to context and purpose;
2. Model and analyse the engineering behaviours of soil, rock and groundwater to design foundations, earthworks and reinforcements for built structures like mines, tunnels, dams, buildings, bridges and roads, landfill sites and offshore structures;
3. Practice as professionals by effectively managing their own time, documenting and communicating their professional activities and undertaking self-review to guide continued professional development

The TLOs provide a general framework that could be used for any engineering program. The one component that could/should be customised is the third one: Abstraction and Modelling. It is this component that distinguishes the various branches of engineering. For Geotechnical Engineering at SoE, this became PLO number 2 above.

ULOs in the style of TLOs

There needs to be a clear relationship between each specialisation's PLOs and vertical integration of unit learning outcomes (ULOs) from first year onwards, leading to attainment of the PLO (Figure 1). Table 2 compares a set of pre-existing ULOs which covered unit content and graduate attribute learning for a second year electronics engineering unit (left hand column), and how those ULOs wererewritten in the style of PLOs, and hence TLOs (right hand column). In the curriculum structure model we are advocating, the ULOS are related directly to unit assessment tasks and the link between PLOs and ULOs completes the curriculum structure loop. A good example of mapping assessment tasks direct to EA Competencies is provided by Willey and others (Willey et al., 2008). As is apparent from Table 2, ULOs are similar in wording and intent to PLOs but content and verb (attainment) vary by year level. These could be developed in line with Bloom's Taxonomy descriptors however, a simple progression of attainment descriptors would only be workable if the content descriptor remained static. The link between PLOs, ULOs and unit assessment demonstrates the concept of a curriculum structure or framework operating at assessment level, through unit level, to program level.

Table 2 – Unit Learning Outcomes for a second year electrical engineering unit written in two styles.

<table>
<tr><th>Pre-existing ULOs
(content and graduate attributes separate)</th><th>New ULOs
(content and graduate attributes integrated)</th></tr>
<tr><td>Recognise digital electronic circuit architectures</td><td rowspan="2">Undertake independent problem identification and source additional knowledge to propose digital architectures that could resolve identified problems</td></tr>
<tr><td>Demonstrate understanding of digital electronic circuits and systems</td></tr>
<tr><td>Analyse digital electronic circuits</td><td rowspan="2">Design digital electronic systems for real-world applications that incorporate microprocessors and microcontrollers, gate circuits, and combinatorial and sequential circuits</td></tr>
<tr><td>Evaluate the functionality of different digital architectures</td></tr>
<tr><td>Design digital electronic circuits</td><td rowspan="2">Apply appropriate number systems and assembler language techniques during digital electronic system design</td></tr>
<tr><td>Apply knowledge of electronic engineering fundamentals</td></tr>
<tr><td>Demonstrate in-depth technical competence in electronic systems</td><td>Contribute to the success of a team solving an electronic systems problem</td></tr>
</table>

Undertake problem identification, formulation and solution	
Communicate in the technical language used in the field of electronics	Communicate solutions to electronic systems problems in lay terms, and in the technical language used in the field of electronics
Independently learn to solve problems requiring additional knowledge	
Work as a team member in laboratory sessions	

EA Proportions of total learning experience

One of the activities undertaken during the mapping of the undergraduate engineering curriculum at UTAS for EA accreditation was an analysis of how the Stage 1 Competencies (Engineers Australia, 2011) and EA's recommended portions of total learning experience (Engineers Australia, 2008) fitted together. Each of the 54 units in the engineering curriculum identified one or more Stage 1 competencies that were assessed in that unit. Calculating the proportions of total learning experience (TLE) required mapping of the 16 EA Stage 1 Competencies onto the five TLE categories:

1. mathematics, science, engineering principles, skills and tools appropriate to the discipline of study (not less than 40%),
2. engineering design and projects (approximately 20%),
3. an engineering discipline specialisation (approximately 20%),
4. integrated exposure to professional engineering practice, including management and professional ethics (approximately 10%),
5. more of any of the above elements, or other elective studies (approximately 10%).

The EA accreditation documentation asks for the TLEs for each specialistion

It was found that there was not a good fit between the TLE categories and the EA Stage 1 Competencies. Some competencies mapped convincingly, for example 1.2 "Conceptual understanding of the mathematics, numerical analysis, statistics, and computer and information sciences which underpin the engineering discipline" mapped clearly to TLE 1 (above). But the mapping was less clear for other competencies. For example, should EA Stage 1 Competency 2.1 "Application of established engineering methods to complex engineering problem solving" map to TLE 2 (design) or TLE3 (discipline specialisation). The EA 'Indicators of Attainment' further confused the issue: 2.1 (d) mentioned design, whereas 2.1 (f) mentioned specialisations. TLE category 1 was considered to be not applicable to the UTAS BE degree that has no elective studies. EA Stage 1 competencies 3.2, 3.3 and 3.6 did not appear to relate to any of the TLE categories and thus were not included in the mapping.

Notwithstanding some of the judgment calls that needed to be made, the SoE developed the mapping shown in Table 1 for use in the SoE's 2013 application for accreditation. To the best of our knowledge this is the first time such a mapping has been done.

Table 3: Total learning experience category mapped to EA Stage 1 Competency mapping

Total learning experience category	EA Stage 1 Competencies
1. Mathematics, science, engineering principles etc.	1.1, 1.2, 1.4, 1.5
2. Engineering design and projects	2.2, 2.3, 2.4
3. Engineering discipline specialisation	1.3, 1.6, 2.1

4. Integrated exposure to professional engineering practice etc.	3.1, 3.4

Once Stage 1 Competencies had been assigned to all the curriculum elements (units) of an engineering degree specialisation it was a straightforward process to calculate the proportions of the TLE in each specialisation using the mapping in Table 1.

It should be noted that a particular unit may deliver learning associated with one, two, three or more EA Stage 1 Competencies. In such a case the contribution of this unit was divided between the respective TLE categories. For example, in the case of UTAS unit KNE354 *Thermal Engineering 1*, that delivered learning associated with EA Stage 1 Competencies 2.1 and 2.2, there a 50% contribution to TLE category 2 and a 50% contribution to TLE category 3.

Curriculum mapping at SoE

In previous years, the SoE pioneered the conversational approach to mapping engineering curriculum (Carew et al., 2008). Based on this approach and similar approaches developed and used elsewhere (Goldfinch et al., 2007; Symes et al, 2011a;) , a more streamlined approach was used in 2013 to document the relationship between ULOs, assessment tasks and the EA Stage 1 Competencies. Every unit in each of the specialisations of the SoE BE contributes to development of one or more of the EA Stage 1 Competencies.

The process was as follows:

1. The Unit Coordinator, acting under the guidance of the specialisation leader, designs the unit content and methods of assessment and prepares the unit guidelines for approval by the Head of School.
2. Significant changes to unit level curriculum, learning outcomes, or assessment are discussed by the Curriculum Committee and the SOE T&L Committee provides a recommendation to the HoS. This process is particularly important for units that are common in more than one stream.
3. The UTAS School of Engineering Curriculum Committee decides which of the EA Competencies are best delivered and assessed in the program and the required information is included in the unit outlines. The list of competencies delivered in each unit is not exhaustive; there could be more competencies claimed for a unit, particularly if assessments were aimed at a particular competency.

For the 2013 mapping for EA accreditation, Unit coordinators were asked to rate their assessment against the EA Stage 1 Competency standards on a scale of 1 to 3 where:

1. the element of competency had been **indirectly** assessed; the subject matter, activities, teaching program and learning outcomes were designed to develop the competence.
2. the element of competency had been **partially** assessed, and
3. the element of competency had been **directly** assessed in this unit.

In no instance was there a claim for competency that was assessed but not taught.

Most of the competencies claimed by a particular unit were assessed directly. Some were partially assessed; for example in the unit KNE211 *Engineering Design and Project Management* EA Competency *3.5 Orderly management of self, and professional conduct* was partially assessed. Students had multiple tasks to prepare and report on a strict deadline with penalties for late submission. This necessitated prioritization given the requirements of other units.

Some competencies were claimed indirectly, for example in the unit KNE240 *Reliability Engineering*, Competency *3.3 Creativity, innovative and pro-active demeanour* was indirectly assessed: The subject matter and in-class activities were designed to develop this competence.

Mapping curriculum at NCMEH

Leading up to the 2010 accreditation, NCMEH reviewed the objectives and outcomes of the three programmes, together with the relevant graduate attributes to develop a new single structure that encompassed all three degrees. The structure incorporated the degree objectives, outcomes and attributes, thus integrating the technical and generic outcomes and linking them directly to EA's Stage 1 Competencies. In order to assess and track the attainment of the degree outcomes and attributes, NCMEH established a process where unit outcomes are updated at the same time as new degree outcomes, and this exercise is used to refresh unit outcomes and ensure they align with the course outcomes and represent good teaching and learning practise.

During the NCMEH 2010 process an *assessment criteria* sheet was developed for each unit (Symes et al, 2011b). The assessment criteria sheets identified the scope of the each unit's assessments and mapped them against the unit outcomes and Degree Objectives. The relationship of assessments to unit outcomes is tracked using a database developed by NCMEH for auditing and mapping the teaching and learning of graduate attributes.

The database and mapping process described in Symes, Ranthumugala, and Carew (2011a), allowed the Unit Coordinator to track two metrics against the unit teaching of the attributes and the assessments. The first being an "Average Teach Rating" as an indicator of teaching 'input'; that is the extent of effort and time committed by academics to teaching each degree objective. The teach rating provides a rough measure of the exposure and potential for learning that students have for each degree objective. The second being an "Average Percentage of Final Mark", which gives an indication of the extent to which the assessments address the degree outcomes. A rating of '0' signifies the outcome is not covered while a rating of '3' signifies the outcome was a major focus of the unit. The data is collated and averaged for each of the years of study providing quantitative evidence as to whether all of the degree objectives are being taught and assessed across the curriculum.

Conclusions: lessons for practice

This paper presents a logical framework that connects and quantifies the various parameters used to assess the quality and professional acceptability of an engineering degree. What does the suite of ideas presented in this paper mean, in practice, for engineering curriculum (re)structure and ongoing management?

SoE

Whereas, in past accreditation applications, there was room for opinion as to what Competencies were delivered, and how Total Learning Experience targets were met, the SoE can now justify such assertions by direct reference to assessments. We now have clear Program Level Objectives and Unit Level Outcomes.

One valuable outcome for SoE has been identification of EA Competencies delivered in each curriculum unit, and their inclusion in Unit Outlines. This means lecturing staff and students are aware of the contribution that a particular unit makes to the overall competency make-up of a professional engineer. But it is not a static process; Unit Coordinators (with an awareness of the overall competency picture) are free to change their subject matter and assessment methods to rectify any perceived deficiencies. These changes are tracked by the School's Curriculum Committee.

For SoE, the mapping of assessment tasks to EA competencies for the 54 units in the engineering curriculum took approximately 120 man-hours. This was the most time consuming of the mapping processes. Previous accreditation mappings were significantly different due to the change in EA requirements from Graduate Attributes (a-j, pre-2004) to Stage 1 Competencies (now 16 elements of competency). This current mapping process was initiated by reviewing unit outline documentation, then discussing the mapping with unit coordinators on a 1-to-1 basis to confirm and refine the result. The results were subjected to review and discussion by the SoE Curriculum and then the SoE T&L Committee.

The pending SoE accreditation has clearly proved to be the main driver for this exercise; however it should be noted that the mapping documents developed provide a well defined and practical framework for evaluating the impact of future unit and course changes on the program. It is also very important to support the development of the documents with organisational processes so that they may be maintained as 'live' documents for ongoing use.

NCMEH

Since accreditation in 2010, NCMEH has embarked on a path to develop a single structure; a common set of degree outcomes and attributes for the three specialisations offered at NCMEH, linked to EA Competencies. The emergent degree outcomes and attributes incorporated and integrated the course technical and generic outcomes and attributes (much like the ULOs described above). The development of these outcomes and attributes involved lengthy consultation and negotiation processes with internal and external stakeholders, providing an outcome that represented an all-encompassing structure and a clear and comprehensive statement of the graduate qualities, knowledge, and experience specific to graduates from NCMEH engineering degrees tracked through the use of a database system.

One extra benefit is that we now have a set of concise documents that allow us to easily induct a new staff member into a whole-of-program view, so that they can quickly see where their part fits, what competencies their units develop, and the connections they can help students make into surrounding units. This is a substantial step forward from previous documentation.

Finally, we are now well set for the next round of accreditation since the spreadsheets developed only need regular updating rather than the complete analysis required this time.

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