An Engineering Approach to Engineering Curriculum Design

Michael Liebelt[a], Stephanie Eglinton-Warner[b], Wen Soong[a], Said F. Al-Sarawi[a], Brian Ng[a], Braden Phillips[a], Matthew Sorell[a]

School of Electrical and Electronic Engineering[a], School of Education[b], University of Adelaide
Corresponding Author Email: michael.liebelt@adelaide.edu.au

CONTEXT

The School of Electrical and Electronic Engineering at the University of Adelaide has for many years been offering a range of Electrical and Electronic Engineering degrees in several specialisations. By 2013 a range of external factors had combined to motivate a major review of the curriculum for all of these qualifications

PURPOSE

There were several drivers for the review, including: the need to ensure AQF level 8 compliance; changes to University policies since the previous revision; and recommendations from internal reviews and accreditation processes. The primary motivation however was to refresh the technical content of the program and to ensure that learning outcomes are aligned to Engineers Australia Stage 1 Competency standards, the evolving needs of employers, and research education outcomes.

APPROACH

Once the need for a major curriculum revision had been established, the challenge was to achieve a School-wide transformation in mindset, from the entrenched content-based approach to a pervasive outcomes-oriented approach. We describe the process we used to achieve this transformation through a structured top-down design approach, maintaining clear traceability to the objectives of the review. The working group leading the curriculum review was encouraged to ‘think like engineers’ by first considering the project specifications (i.e., the skill and competency profile that we wanted to achieve for the Adelaide Electrical and Electronic Engineering graduate), and then applying design principles and a systems perspective to the task at hand.

RESULTS

The new curriculum commenced operation for the first time in 2016. The new curriculum is more coherent and better focussed than the previous version, offering more flexibility to students in choosing their preferred area of specialisation. Feedback indicated that we did not achieve all of our learning and student engagement objectives in the first year courses, so the pedagogy has been reviewed and fine-tuned for the 2017 delivery.

CONCLUSIONS

At this stage of implementation of the new program we are confident that the new curriculum is working well, providing more flexibility for students and showing a clearer alignment to defined learning outcomes. We expect that by the end of the year we will have sufficient feedback from students to ascertain whether we have improved the student experience and program coherence from their point of view.

KEYWORDS

Curriculum renewal; outcomes-based design; systems approach; curriculum design principles; constructive alignment.

Introduction

The School of Electrical and Electronic Engineering (The School) at the University of Adelaide has offered degrees in electrical engineering since 1946. Following developments in the discipline, the original electrical engineering degree was renamed Electrical and Electronic Engineering in the 1980s and was later expanded to add a family of named degrees in Computer Systems Engineering, Telecommunications Engineering, and Electrical and Sustainable Energy Engineering, all based on a common mathematics, fundamental science and electrical engineering science core. Throughout this evolution the School has balanced the introduction of new technologies with the displacement from the curriculum of fundamental science, but without a systematic review of pedagogy or program objectives.

By 2013 the School had become sensitised to the need to undertake a substantial curriculum review because the pressures to introduce new technology content could no longer be managed by this process of displacement. It was clear that a considered re-evaluation of what is the essential knowledge for an electrical and electronic engineering graduate would be necessary to produce a new program that could form the basis of education in the discipline over the next decade or more. At the same time the School was dealing with a relatively flat demand for the degree by school leavers, following the collapse in demand for ICT-oriented programs in the early 2000s.

External pressures were another significant driver for comprehensive change. New provisions in University policy required additional generic content in all programs, most significantly the inclusion of non-cognate elective options. The University also required explicit curriculum structures to meet the AQF criteria for Level 8 Bachelor (Hons) degrees. Successive Engineers Australia (EA) accreditation reports urged embedding professional competencies throughout the program. Importantly, it was also becoming clear that specialised named degrees were declining in popularity as, in the tight post-GFC employment market, students were looking for more generic and portable qualifications.

It was clear, given the multiplicity of constraints that would have to be satisfied, that some difficult compromises would be required and that we would need a robust set of criteria for making these compromises. Meeting all these demands would be difficult to accommodate with incremental changes to the existing structure.

Against this background the School resolved to undertake a comprehensive ground-up redesign of its undergraduate engineering programs – probably the most extensive change to the program in its history. Serendipitously, this coincided with a University-wide project to introduce a whole of program curriculum development approach (Curriculum Renewal), enabling access to curriculum design support.

At the outset, we committed to focusing on the graduate outcomes of the program, viewing all current content in the program as being potentially disposable. This was a substantial change of philosophy for what had long been a content-focussed curriculum. The University sponsored Curriculum Renewal approach was grounded in Constructive Alignment principles promoted by Australian education researchers (Biggs & Tang 2007; Oliver 2011; Lawson 2014). These approaches did not, however, take a discipline focussed approach, e.g. ‘thinking like engineers’ for engineering curriculum or ‘thinking like managers’ for management curriculum. Nor did they consider the integrated and complex relationships between progression across the degree and learning outcomes at the course level and at the degree level. They did, though, consider development of professionally relevant competencies in some cases.

Project Curriculum Design Conceptualisation

The task of developing a proposal for a revised curriculum was placed in the hands of a curriculum design team comprising the authors – academics in the School of Electrical and Electronic Engineering and a curriculum design specialist (Eglinton Warner) who was assigned to the project by the Deputy Vice-Chancellor (Academic)’s office as part of the Curriculum Renewal project. The academics on this team were selected for pragmatic reasons as well as for their interest in the proposed work. This team represented a range of sub-disciplines within electrical and electronic engineering and teaching expertise at each year level within the degree. They were also a team small enough to be able to make time to engage in the deep and robust exploration of issues and ideas within the relatively short timeframe set by the University to demonstrate outcomes from the Curriculum Renewal project. It was always intended that this team, at the conclusion of the University sponsored project, would become a critical core who would then continue the work by engaging with and building capability of colleagues throughout the School and the other engineering schools within the Faculty.

The University's Curriculum Renewal approach, grounded in Constructive Alignment (Biggs & Tang 2007) conceives degrees and their courses as a system. In this system the learning intentions at the degree level (Program Learning Outcomes) are achieved by the integrated and aligned interactions of the learning intentions at the course level (Course Learning Outcomes), developed through the learning activities and confirmed through the assessments. Collectively the course assessments provide evidence of the progress towards and achievement of the Program Learning Outcomes (Baume 2009). Applying this in the context of engineering the work of the team was also influenced by work done at MIT (Crawley 2001; Crawley, Malmqvist, Lucas & Brodeur 2011) using a multiple perspectives and whole of degree approach to inclusion of professional as well as technical skills in engineering degrees. It was also influenced by Toral, Martınez-Torres, Barrero, Gallardo & Duran (2007) and Cornwell (1996) who used concept mapping to inform curriculum design. Design principles (Lidwell, Holden & Butler 2003) were also considered when developing a conceptual framework within which to operate. Based on initial review of available literature at the time, combining these approaches and conceptualising curriculum design as an engineering problem had not yet been applied in practice in Australia.

For this engineering problem (i.e. curriculum design) the required outputs in the form of graduate outcomes were known (or at least would be agreed on by the stakeholders), the raw materials and the external constraints were given, so the problem reduced to determining a process to achieve the required outputs subject to these constraints – a standard engineering design process. Framing the problem at hand as a need to achieve certain outcomes subject to numerous non-negotiable constraints was key to securing acceptance of the idea that a completely new program design would be necessary and that it was inevitable that some of the existing program content would be discarded – at least from the program core.

The team executed the project by following the decomposition and definition stages captured in the left hand side of the well-known system engineering V diagram (Forsberg and Mooz, 1991). The integration and verification process on the right hand side of the V diagram is being executed as a combination of outcomes mapping processes and progressive course implementation. We will discuss this stage of the process in more detail towards the end of this paper.

Decomposition and Definition

Program Learning Outcomes and Technical Skills Profile

We conceptualised the User Requirements for our system as being a combination of the Program Learning Outcomes (PLOs) and the Technical Skills Profile (TSP) that should be developed in our graduates. The PLOs were adapted from the outcomes that had been developed in the process of revising the programs for AQF Level 8 compliance in 2015. They strongly reflected the Engineers Australia Stage 1 Professional Competency Standard (Engineers Australia, 2013) and the mandated University Graduate Attributes. Consequently, the PLOs were largely focussed on generic professional and engineering competencies and provided little detail about specific technical and scientific knowledge and application abilities of graduates. The team was of the view that our PLOs would be unlikely to be very different from those of many other electrical and electronic engineering programs accredited by EA. On the other hand, the School did have a firm view that its graduates would be distinguished by their profile of mathematical abilities, scientific knowledge and breadth of exposure to electrical engineering science. The TSP was therefore considered to be an essential part of the output specification for our graduates. We agreed, early on, that our graduates should be characterised by a broad knowledge of the fundamental principles and technologies, with a strong foundation in the underpinning mathematics and (to a lesser extent) science.

Arriving at an agreed technical skills profile was perhaps the most contentious step in the process. We used a mapping process to capture the views of those in the working group on what is essential, desirable or optional knowledge for our graduates. We began by brainstorming to identify all of the areas of knowledge that might reasonably be considered for inclusion in the new curriculum. These views were unquestionably influenced by the areas of technical expertise of the individuals in the group, but because the team represented the broad range of specialisations within the School, a wide range of views and perspectives was captured. The group was large enough to be representative, but small enough to reach consensus in a pragmatic way. We initially constructed a table of skill sets that each member of the initial design team considered to be essential, desirable or neither for graduates on each specialisation. A section of this table is shown in Table 1.

Table 1: Initial Assessment of Content (partial map shown)

E = Essential D = Desirable *_ if neither*	B Eng (EE)	Energy Specialisation	Telecommunications Specialisation	Computer Engineering Specialisation
Science				
• Newtonian mechanics - linear and rotational	EEEEE	E_EEE	E__EE	E_DEE
• electromagnetics	EEEEE	E_EEE	E_DEE	E_DEE
• electrostatics	EEEEE	E_EEE	E_DEE	EEDEE
• solid state physics	EDEDD	E_DD_	E_DD_	EDEDD
• relativity - quantum mechanics	D_D__	__D__	_____	_____
• optics	D_DD_	___D_	D_DD_	D__D_
• material properties	D_DDD	D_DEE	___DD	___ED
• thermodynamics	D_DED	E_EEE	D__DD	D__DD
• biology	D_DD_	___D_	___D_	___D_
• chemistry	D_DD_	D_DD_	D__D_	D_DD_
• psychology	D_D__	D_D__	D_D__	D_D__
• philosophy & logic	D_D__	D____	D_D__	D____
Energy				
• machines	EEEEE	E_EEE	___DD	D_DDD
• power electronics	EEEEE	E_EEE	____D	D_D_D
• power systems	EEEEE	E_EEE	D___D	D_D_D
• energy sources	EDDEE	E_EEE	D__DD	D_DDD

Table 2: Theme Map (partial map shown)

THEMES	RELEVANCE				BREADTH x DEPTH				TIMING
PROGRAMS	EEE	Energy	Tele	Comp	EEE	Energy	Tele	Comp	
1. **Software and Programming**	A	C	A	A	b d	- d	B d	B d	E
2. **Energy processing** *(conversion and transportation)*	B	A	C	C	B d	B D	b -	b -	V
3. **Communication Networks** *(topology, dimensioning, protocols, systems and standards)*	B	B	A	B	b -	b -	B d	b -	L
4. **Signal Processing** *(discrete and continuous time)*	A	B	A	B	B d	b d	B d	b d	M
5. **Practical Electrotechnology** *(solder, assemble, PCB, components)*	B	B	C	B	b d	b d	b -	b d	E
6. **Systems Engineering** *(entire lifecycle - design, standards, requirements - holistic view, interactions, unique language & methodologies)*	A	A	A	A	b d	b d	b D	b d	V

Themes

After discussion and debate based on the level of support that different topics received in this initial matrix, the topics were refined and aggregated into themes. Themes were classified according to their level of importance to each specialisation expressed in the first map. The group then debated and agreed upon the level, breadth and depth of coverage of each theme on each specialisation and the approximate position of the coverage on the program – early, middle or late. Table 2 shows a section of the themes map. The importance of each theme is coded as A, B, or C in the left hand section of the table. On the right the extent of breadth and depth of coverage agreed for each theme is indicated by a capital B/D, lower case b/d or a hyphen -. The approximate location on the curriculum is indicated in the last column by E, M or L for early, middle or late. A "V" in this column indicates that a theme should be pervasive throughout the curriculum. Finally, a theme is shaded for a specialisation if it is a distinctive theme for that specialisation. Dark purple shading in the case of Systems Engineering indicates that the theme is intended to be a distinguishing characteristic of all versions of the program.

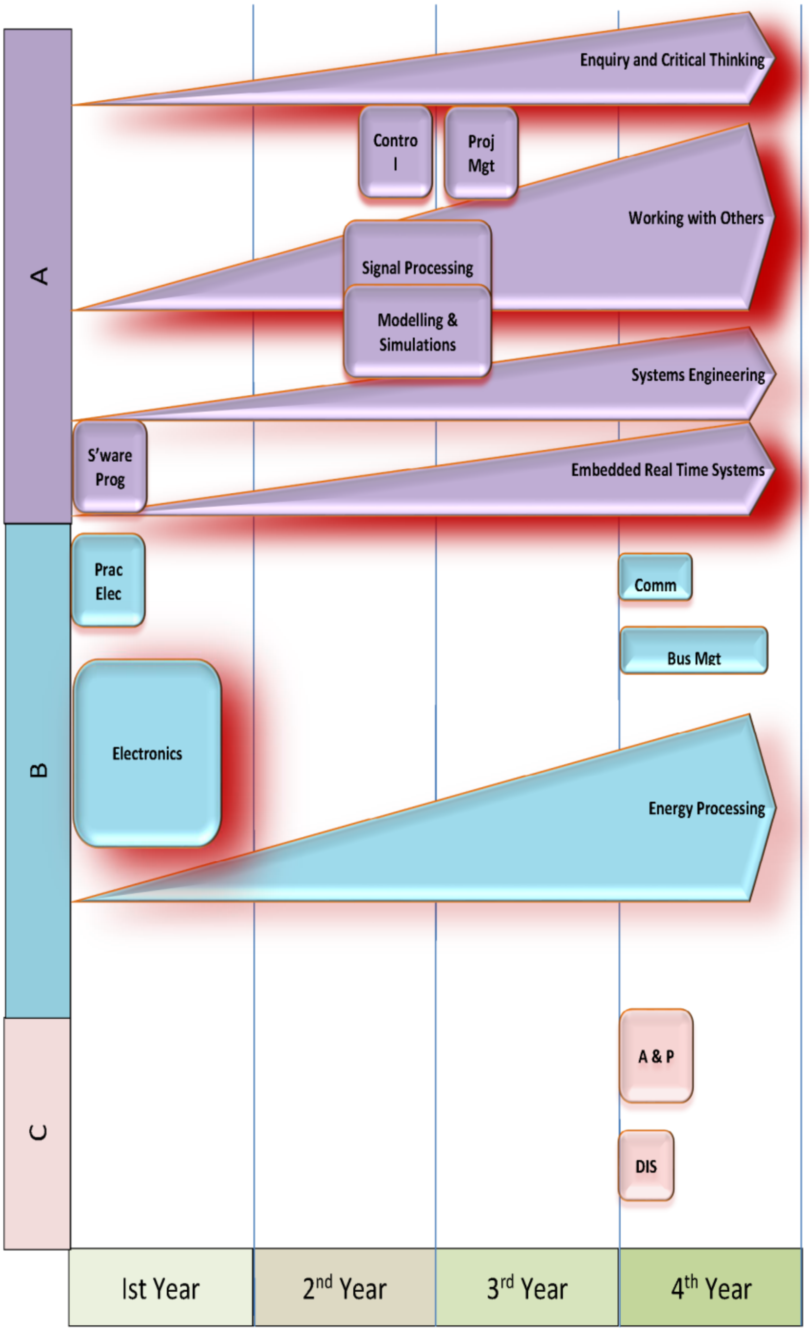

Figure 1: Dimensioning and Positioning Themes

As a final graphic aid to understanding the emphasis and trade-offs in each version of the program, the information contained in the themes map was translated into a graphic showing the timing, breadth and depth of each theme. We experimented with several graphical representations of the space each theme would occupy in the different versions of the program, eventually settling on the form shown in Figure 1. The size of each object in this diagram is meant to indicate breadth, and the intensity of the shadow its depth. A thickening object indicates progressive development over two or more years.

The next step was to rationalise the content by compressing the various sized and shaped themes into the four-year duration of each program. This was a stage involving many compromises, but we deliberately kept discussion at a high conceptual level, allowing us to make decisions based on high-level learning outcomes rather than attachment to specific content. A snap shot of this result is shown in Figure 2.

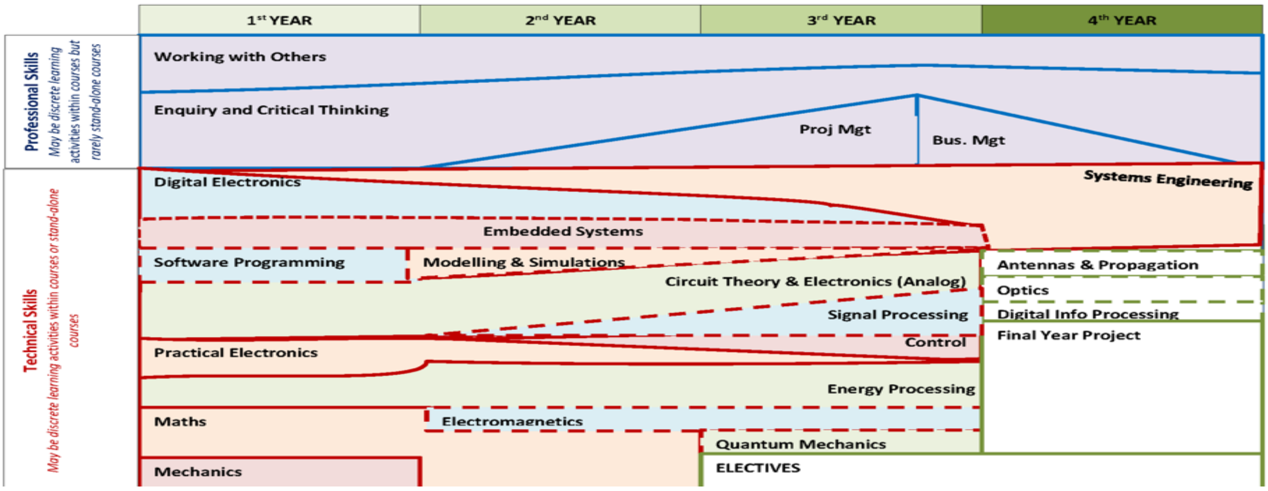

Figure 2: Distribution of Broadly Defined Knowledge and Competencies across the Degree

Courses

Themes were then divided into courses, forcing further compromises as minor topics were merged and larger topics were rounded up or down to fit standard course sizes. This resulted in the more conventional 4x8 course map shown in Figure 3. There was a deliberate attempt to keep course titles aligned to themes, rather than reflecting specific content. Different coloured shading reflects different themes.

YEAR 1	YEAR 2	YEAR 3	YEAR 4
MATHS I	MATHS II	Specialist topic	RESEARCH PROJECT
		SIGNAL PROCESSING AND CONTROL	
CIRCUITS AND ELECTRONICS A	CIRCUITS AND ELECTRONICS B	CIRCUITS AND ELECTRONICS C	
DIGITAL ELECTRONICS AND EMBEDDED SYSTEMS A	DIGITAL ELECTRONICS AND EMBEDDED SYSTEMS B	DIGITAL ELECTRONICS AND EMBEDDED SYSTEMS C	BUSINESS MANAGEMENT
ENERGY A	ENERGY B	ENERGY C	Specialist Topic
SOFTWARE PROGRAMMING	MODELLING AND SIMULATIONS	PROJECT MANAGEMENT	Specialist Topic
PRACTICAL ELECTROTECHNOLOGY*	SYSTEMS ENGINEERING A	SYSTEMS ENGINEERING B	SYSTEMS ENGINEERING C
MECHANICS	ELECTROMAGNETICS	QUANTUM MECHANICS	Specialist Topic

Figure 3: Preliminary Course Map

Then individual course design commenced, identifying course learning outcomes and titles. We recognised the danger of losing alignment to program learning outcomes at this stage so we tabulated each course with its learning outcomes under the theme of which it was part and ensured that the progressive development of Course Learning Outcomes within a theme aligned to the technical and/or professional learning outcomes that they were designed to serve. Toward the end of this task, we decided to implement each specialisation as a major within the Electrical and Electronic Engineering program. Figure 4 shows an extract from the early mapping under Majors. While this added a further constraint, as we committed to keeping the core of the program common in the first two years, enabling students to choose their major at the start of third year proved to be one that was relatively easy to accommodate because of the earlier decision we had made about the positioning of foundational topics in the early part of the program.

BE(HONS)EE PROGRAM LEARNING			ELECTRICAL AND ELECTRONIC MAJOR	ELECTRICAL SUSTAINABILITY ENERGY MAJOR	T
By the end of the Bachelor of Engineering (Honours) (Electrical and Electronic) program Graduates will...			*To develop and apply the skills and knowledge to develop and design electrical and electronic devices, machines and systems suitable for a range of applications*	*To develop and apply the skills and knowledge to develop and design high performance and low cost renewable energy systems*	*T c r*
KNOWLEDGE	1	Have knowledge of the comprehensive theory underpinning natural and physical sciences and the engineering fundamentals applicable to the electrical and electronic engineering discipline	Principles of Electronic Systems Foundations in Digital Systems Introduction to Programming for Engineers Introduction to Electrical Engineering Analysis and Application of Electronic Circuits Digital Systems Electric Energy Conversion Object-Oriented Programming for Engineers Control Digital Signal Processing	Principles of Electronic Systems Foundations in Digital Systems Introduction to Programming for Engineers Introduction to Electrical Engineering Analysis and Application of Electronic Circuits Digital Systems Electric Energy Conversion Object-Oriented Programming for Engineers Control Digital Signal Processing	F F I I A D E O C D
SKILLS & APPLICATION	5	Be able to think critically, and to apply logic and exercise judgement, in analysis, design and decision making in contexts relevant to electrical and electronic engineering	Introduction to Electrical Engineering Systems Engineering A Systems Engineering B Project Management Business Management Systems Electrical and Electronic Research Project Principles of Electronic Systems Foundations in Digital Systems Analysis and Application of Electronic Circuits Digital Systems	Introduction to Electrical Engineering Systems Engineering A Systems Engineering B Project Management Business Management Systems Electrical Sustainable Energy Research Project Principles of Electronic Systems Foundations in Digital Systems Analysis and Application of Electronic Circuits Digital Systems	I S S P B T P F A D
	7	Be able to apply their	Introduction to Electrical Engineering	Introduction to Electrical Engineering	I

Figure 4: Mapping against Majors

Integration and Verification

The program design was completed and approved in 2014 and introduced for students commencing in 2016. To manage the workload of implementing such a comprehensive curriculum review we are implementing the new course year by year. We are currently in the process of teaching the first year of the program for the second time and the first offering of the new second year, so we are in the relatively early stages of integration and verification. In the system engineering language of Forsberg (Forsberg and Mooz, 1991) our courses are the configuration items and we have so far designed and implemented two at level 1, four at level 2 and are in the process of designing the level 3 courses. In all cases the courses have been designed to the Course Learning Outcomes specified in the Decomposition and Definition stage.

The development of courses has involved the initial design team consulting and collaborating with, advising and supporting colleagues. They have used their deeper understanding of the processes, underpinning theories and justifications of the design developed through the initial Curriculum Renewal project to build understanding and ‘buy-in’ of colleagues. This was integral for the longer term plans of the School (i.e. beyond the initial 9 month project) as it was assumed that successful implementation required the informed consent and engagement of academics within the School and other engineering schools within the Faculty.

Verification of the full system design will of course not be possible until our first graduates emerge at the end of 2019 when we will solicit feedback from both graduates and employers. In the meantime we are verifying the outcomes of individual courses using the usual indicators: student satisfaction rates, pass rates and average marks. We also completed a retrospective map of the course learning outcome and assessment activities to program learning outcomes, EA Stage 1 Competencies and University graduate attributes, as part of preparation for a regular accreditation review in 2017. The approach taken to curriculum mapping, grounded in Constructive Alignment principles, using common tools (e.g. MS Excel) to represent complex relationships, has allowed the integrity of the degree as a whole to be visualised, analysed and evaluated. Review of all this data has validated our design.

Feedback from students on individual courses has been variable. In particular it is clear that we have attempted to cover too much ground in the first attempt at one of the first year courses and we are making changes to that (with consequent changes to one of the level 2 courses).

Conclusion

We believe that with this approach to curriculum design we achieved a fundamental change in the philosophy of engineering curriculum design within our institution. The focus on program learning outcomes and technical skills profile as the output of our programs has relieved us from the debilitating focus on content. The traceability of course learning outcomes and course design and implementation to program requirements, through a conventional engineering decomposition and definition process, has been crucial in securing both buy-in and support from our academic colleagues and University-level approvals for the curriculum. It will also be the key to adapting the program as we proceed with the integration and verification phase over the next two years: adapting course design to respond to observed student learning outcomes and to student and employer feedback. By ensuring all elements in the degree (timing, depth, breadth, content, program and course learning outcomes, assessment and learning activities) are explicitly aligned and monitored by the curriculum mapping and review processes, any future changes and refinements can be tracked and considered to ensure the integrity of the system is maintained.

It was expected that a comprehensive curriculum revision like this was going to challenge some long held views about the primacy of content in an engineering curriculum. On reflection, we could have beneficially engaged with a broader group of colleagues at the outset, particularly in defining the technical skills profile. Nevertheless, by adopting an engineering design approach we have been able to completely justify our proposed changes by demonstrating that the design can be traced back to agreed outcomes specifications. Furthermore, the proposed approach is applicable to other engineering curriculum design and nothing prevents its utilisation in other disciplines. Indeed this project has been used as an example of effective curriculum review and design practices by the education specialist on the team, with other Schools and Faculties across the University.

Acknowledgement

The authors would like to thank academic staff in the School of Electrical and Electronic Engineering for their insightful discussion and feedback.

References

Baume, D. (2009). *Writing and Using Good Learning Outcomes*, Leeds Metropolitan University. Retrieved 15 September 2017 from http://eprints.leedsbeckett.ac.uk/2837/1/Learning_Outcomes.pdf

Biggs, John and Tang, Catherine. (2007). *Teaching for Quality Learning at University*, 3rd edition. Open University Press McGraw-Hill Education, UK

Cornwell Phillip J. (1996) *Concept Maps in the Mechanical Engineering Curriculum*, American Society for Engineering Education 1996 Annual Conference Proceedings

Crawley, Edward F. (2001). *The CDIO syllabus: A statement of goals for undergraduate engineering education*. Retrieved 28 September 2017 from http://www.cdio.org/files/CDIO_Syllabus_Report.pdf.

Crawley, E.F., Malmqvist, J., Lucas, W.A. and Brodeur, D.R. (2011). *The CDIO syllabus v2. 0. An updated statement of goals for engineering education*. In Proceedings of 7th International CDIO Conference, Copenhagen, Denmark.

Engineers Australia, (2013). *Australian Engineering Stage 1 Competency Standards for Professional Engineers* Revision 3. Retrieved 15 September 2017 from https://www.engineersaustralia.org.au/sites/default/files/content-files/2016-12/doc21_p05pe_ea_stage_1_competency_standards_for_pe.pdf

Forsberg, K. and Mooz, H. (1991), The Relationship of System Engineering to the Project Cycle. INCOSE International Symposium, 1: 57–65. doi:10.1002/j.2334-5837.1991.tb01484.x

Lawson, Romy (2014) Curriculum Renewal: Leading the Way, Conference Presentation Hawaii International 12th Annual Conference on Education January 2014

Lidwell, William, Holden, Kritina and Butler, Jill (2003), *Universal principles of design*, Rockport Publishers, Mass

Oliver, B. (2011) *Good practice report: assuring graduate outcomes*, Australian Learning and Teaching Council Ltd., an Australian Government initiative. Retrieved 28 September 2017 from http://www.olt.gov.au/system/files/resources/Assuring%20graduate%20outcomes.%20ALTC%20Good%20practice%20report.%20Oliver%2C%20B%202011.pdf

Toral, S.L. Martınez-Torres, M.R., Barrero, F., Gallardo, S. and Duran, M.J. (2007) "An electronic engineering curriculum design based on concept-mapping techniques", *International Journal of International Journal of Technology and Design Education,* 17:341–356 DOI 10.1007/s10798-007-9042-4