Designing an Integrated Engineering Foundation Course

James Trevelyan
The University of Western Australia
James.Trevelyan@uwa.edu.au

Caroline Baillie
The University of Western Australia
Caroline.Baillie@uwa.edu.au

Cara MacNish
The University of Western Australia
cara@csse.uwa.edu.au

Tyrone Fernando
The University of Western Australia
tyrone@ee.uwa.edu.au

Abstract*: A radical restructure of education at the University of Western Australia necessitated a complete redesign of engineering education programs. Following a review, the faculty adopted an integrated engineering science major with pedagogy based on a combination of variation theory and capability theory, content framed in terms of threshold concepts, and delivery using cooperative peer learning methods. The engineering science major provides an entry pathway to professionally accredited master's degrees in a range of disciplines to serve the needs of students and regional employers. Most students will take a second undergraduate major in science, arts, business or design. The new courses reflect changing needs for graduates with greater capacity for community leadership.*

Introduction

The University of Western Australia has adopted a uniform course structure with three year undergraduate degrees followed by postgraduate degrees (a "3+2" model) for students seeking professional qualifications. There will be five bachelor degrees: science, arts, commerce, design, and philosophy: the last being for a specially selected group of the most talented students at entry. Engineering students will take an engineering science major, most within a science degree. Most will also complete a second major from either science (e.g. physics, mathematics, or computing), commerce, design or arts. All students will study outside their chosen discipline for the equivalent of one full semester to broaden their exposure to different ways of thinking and learning.

The new courses have been designed to help students master the skills they will need to provide community leadership in the 21st century. Students will benefit from better teaching methods with more focus on developing critical thinking and integrating research and communication skill development. They will also learn more about the history of their chosen discipline. There has been a strong focus on agreeing the learning outcomes before designing the assessment strategies and learning experiences that will help students to achieve them. The new courses will also achieve significant efficiencies.

After completing their bachelor's degree, engineering students will then complete a two year professional practice master's degree in their chosen engineering discipline to gain an accredited qualification.

The traditional tension between adequate learning of mathematics and technical fundamentals, professional skills, educational breadth and adequate design experience was resolved by adopting improved teaching methods and allowing a wide choice of second major (or other electives).

The faculty's aim is to provide the best education in Australia and the region in engineering, computing and mathematics. Some of the distinguishing attributes that this program aims to develop in its graduates include:

- Ability to apply their rigorous understanding of technical fundamentals in unfamiliar situations.
- Professional and social skills developed from a deep understanding of professional practice.
- Knowledge and personal contacts to transfer the latest research and technology into practical applications.
- A broad education that has prepared them to be good listeners and articulate communicators with both creative and critical thinking skills.

The need to completely redesign engineering education at UWA was fundamentally driven by the University's adoption of the 3+2 model. However, this radical change aligns well with increasing international perceptions among engineering professional societies, engineering educators and employers that the 4-year BEng no longer provides sufficient preparation for future engineering professionals and leaders. In particular, there is an increasing call for engineers to have "professional skills" in communication, globalization, ethics, diversity, leadership and policy in addition to purely technical skill, and a desire that engineering graduates acquire similar levels of expertise as graduates in other professional disciplines such as architecture, medicine, law etc), and are recognized by the community as professionals of similar standing.

Engineering is changing. In the words of one of our industry advisors:

"There will be an increasing demand in industry for graduates with enhanced skills in the non technical side of their development, particularly in supporting work executed remotely, working with multi-cultural and multi-centre teams and interfacing with stakeholders distributed across the globe. Many of these skills are difficult to find in seasoned personnel."

Developing an educational program with these characteristics is a challenge that has taken extensive time and effort. It required recognition that education is not a matter of cramming as much "content" as possible into an empty vessel, but involves developing the capacity of students to think critically and creatively, to learn independently, to integrate disparate aspects of their knowledge and to constructively harness the efforts of others.

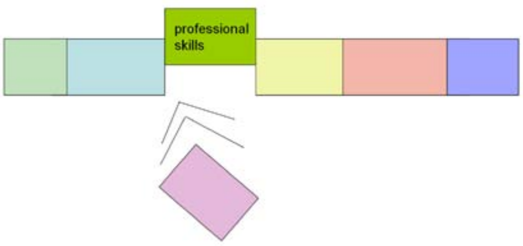

Figure 1: Curriculum design seen as a zero-sum game: new material displaces old material.

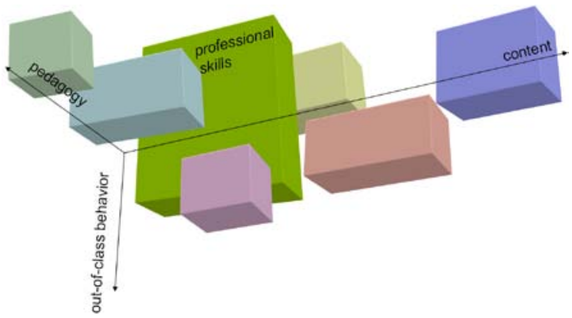

Figure 2: Curriculum design seen in terms of a multi-dimensional space (Trevelyan, 2008).

A view of curriculum design as a "zero-sum" game where new material inevitably dislodges old has led to some apprehension that the adoption of the 3+2 model will reduce the opportunity to teach the technical fundamentals on which all engineering depends (fig 1). It would be easy to see this as a threat which could reduce the opportunity to teach the technical fundamentals on which all engineering depends. Many staff expressed this apprehension early in the design process.

Curriculum design, however, is a multidimensional space in which content is only one of several dimensions (fig 2). Pedagogy, student activities outside formal classes, faculty culture, research culture and other dimensions provide spaces for improvement in many directions without compromising content or intellectual rigour. Recent research demonstrates that it is possible to obtain improvements in academic rigour and professional skills simultaneously (Trevelyan, 2010a, 2010b). These are the kinds of improvements that we decided to pursue.

The on-campus educational experience is a social system in which students interact with teaching staff and other students and, at the same time, with physical objects and abstract information at the core of the discipline. At the same time teachers and students live in the world of work, family and the wider community. Most of the potential for education improvement will come from enriching these social interactions to improve learning. Recent studies have revealed the critical importance of workplace learning and gaining effective transfer from formal education (Eraut, 2000, 2004).

Process

The university initiated broad consultations and discussion on new course structures in mid 2007. A group of full-time staff conducted wide consultations, both within the university and with community stakeholders. Parents, students, schools, employers, and government all contributed their views. A clear need for change emerged by mid 2008. UWA graduates were regarded as highly trained specialists, but many were lacking the skills to engage effectively with their communities and provide effective leadership.

The significant time and resources invested in consultation resulted in a radical change in education at a traditionally conservative university. The change was accepted at the end of 2008 with minimal dissent because the vast majority of the university community understood the need for changes.

Many in the faculty of engineering, computing and mathematics, however, needed more time to grasp the implications of this change. A review of education through the first half of 2009 provided the opportunity for extensive debates on the requirements for the new engineering programs. One of the most consistent messages emerging from workshops, written submissions and consultations made by the review team was an overwhelming desire across the faculty for a coordinated approach to education that encourages teamwork and discourages wasteful competition. Decentralized school-based decision making had created uncoordinated diversity and fragmented, wasteful competition for student load.

The new 3+2 course structure was seen as an opportunity to work together on a coordinated approach to curriculum design. At the same time, we needed to ensure that smaller teams take responsibility for coherent parts of the faculty programme. Like the faculty, it is critical that any group responsible for delivering a teaching programme depends on, and is responsive to funding originating from student enrolments in the programme. However, with appropriate agreement across the faculty, the allocation of funds need not be in strict proportion to student enrolments.

Design of a new engineering curriculum was conceived in terms of:

- Teaching based on a clear understanding of required graduate attributes and abilities
- Design for the best student experience
- Design the best course structure
- Resource allocation that promotes efficiency, quality and learning effectiveness
- Recruiting the best students
- Recruiting the best teachers
- Developing an effective social culture and learning environment
- Using the best education methods
- Using feedback and incremental improvement processes
- Building on workplace internships and part-time work

The 3+2 Course Structure for Engineering

There are three degree cycles. The first is a three-year undergraduate programme leading to a Bachelor degree. The second is a two-year Master degree, and the third is a three-year PhD. Students study 4 units each semester, eight in a year of full-time study as shown in figure 3. The first four units of the engineering science major provide an integrated foundation, supported by four complementary units in mathematics, computation and physics or chemistry. We expect an enrolment close to 900 students, of whom the majority will progress to the professional practice Master degree. Some students may choose to do an additional honours year in which they focus on research skills and an honours dissertation. Master degrees will be offered in several disciplines reflecting student choices and employer needs: chemical, civil, electrical, electronics, environmental, mechanical, mechatronics, mining systems and other disciplines are currently being considered.

Students would also be able to enter through different pathways, as shown in Figure 3.

A distinct feature of this course structure is the second major, providing students the option to develop a foundation in two discipline areas. Engineers can choose a second major to satisfy their educational aspirations in another discipline like mathematics, physics, arts or commerce. Students can choose additional strength in science and mathematics or broaden their education in communication, globalization, ethics, diversity, leadership and policy.

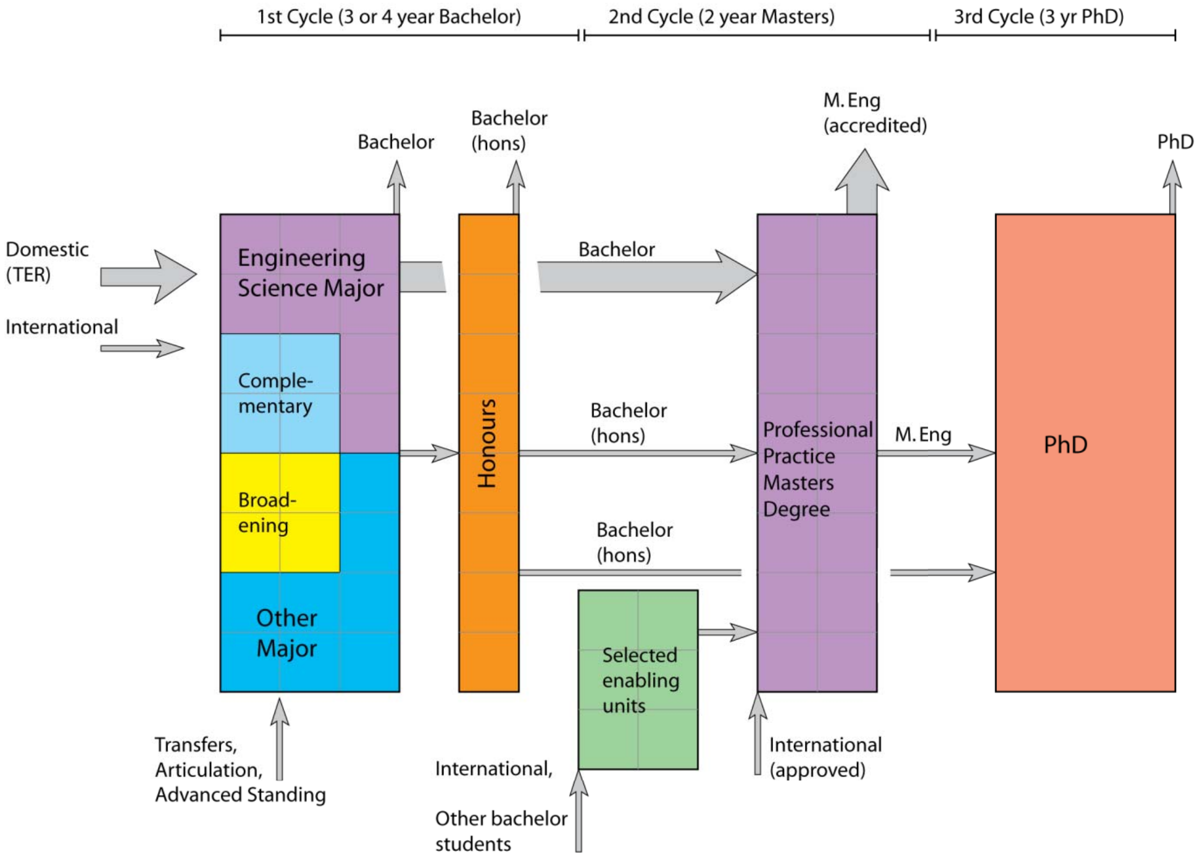

Figure 3: New 3+2 UWA engineering course structure (see text for explanation).

Practicing what we preach

The new curriculum is being designed and will be taught by an interdisciplinary teaching team. To an extent we are living the experience that the students will learn by as they follow us. We have created a supportive team environment and we are providing educational development in a 'just in time' way to the team with workshops on theoretical frameworks, curriculum design, pedagogical approaches and assessment as we move through the process. Just like students, our teaching team are learning in an integrated problem-based way. Course presenters learn the techniques and ways of thinking as they need them to solve their (curriculum) design task. In this endeavour we have the support of the newly launched Faculty Academy for the Scholarship of Education (FASE) which provides an educational scholarship backdrop to the professional development of all staff. The emerging conversations about teaching help to develop and transform the learning environment in the Faculty as a whole. New promotion criteria for the faculty encourage active participation in FASE activities and professional development related to education.

Curriculum development

The plan, at the time of writing, is to teach the four foundation units of the engineering science major as an integrated course block. The course block will be based on enquiry-based active learning in the context of practical engineering applications, facilitated by a team of teachers who will jointly create, teach and assess the course block. Supporting teaching in mathematics, computation and science will be closely linked as their teaching teams follow a similar curriculum design approach. Each unit will include interactive classes with cooperative peer learning and tutoring to support the learning of fundamentals and professional communication skills, as well as project work, and at least one unit will involve a practical build and test component. We are basing the curriculum development on three interconnecting and mutually supportive theoretical frameworks: variation theory (Marton & Pang, 2006), capability theory (Bowden, 2004) and threshold concepts theory (Meyer, Land, & Baillie, 2010). The two former theories guide our overall approach to the 'how' of teaching – we intend to develop student capabilities to different levels, and we will help them learn using the notion of variation theory. The latter theory assists us in designing the 'what' of teaching – what are the critical and yet troublesome thresholds which students must pass through in order to 'think like an engineer'. John Bowden, expert and originator of both capability and variation theory (with Ference Marton) and Erik Meyer (threshold concept theory), are working with us to co-create the new program. We are also developing an adapted threshold capability theory which draws on all three, in order to better understand our task.

Variation theory

Drawing on its founding framework, phenomenography, 'Variation theory' allows us to develop an overarching approach to the integrated design of the curriculum, instead of an *ad hoc* clustering (Bowden & Marton, 1998). The theory is based on the premise that students who are able to discern the variation around critical aspects of an object of study will come to better understand the object in focus. For example, 'day' is understood because of the concept of 'night'. It has been shown that variation around the key critical aspects can influence student perception of the learning environment, which will in turn affect their conception of what learning is and this can alter their approach to learning and ultimately their learning outcome (Booth & Marton, 1997). As such, it allows teachers to design strategies that are most likely to be successful in enabling students to learn with higher order interpretations of the concept (Booth, 2004). Concepts may be learnt in several different ways, in different units of the course block, and students will experience the variation – learning to see the critical aspects of the concept by varying the way in which it is viewed and worked with.

Capability theory

Each unit will progresively develop the students capabilities. It is intended to match the capabilities to be developed to the appropriate teaching approach and to the assessment method using constructive alignment e.g. process capabilities might be assessed through mini projects, group designs, project reports and presentations. Technical fundamentals might be assessed by a mastery exam which tests for the critical threshold concepts that students will need to master to progress to upper years. We are also cognisant of the need to develop students capabilities to the desired level in the foundation units, that they may build on these at higher levels and in the third year streams. By the end of the cycle 2 degree they will have achieved the professional competencies required for engineering practice and this will be easily demonstrable. The levels are based on John Bowden's work on capabilities (Bowden, 2004) which are summarised below with an example of a communication skill.

Scoping level: technical explanation. Basic entry level – the student will be exploring what the capability means and what might be possible. No demonstrable ability necessarily developed e.g. student begins to understand that this is one of the communication skills required for engineers but does not actually develop the skills in the unit.

Enabling level. Some basic abilities are developed without reference to meaning or context e.g. student can present a PowerPoint slide talk

Training level. Specific abilities are developed which relate to the context e.g. students develop the ability to write an engineering report and present engineering data.

Relating level. Here the student will begin to develop a relation between the meaning and context e.g. student will develop the skills to alter the way they present data when discussing with local farmers, technicians or other engineering professionals.

Threshold concept theory

It is furthermore proposed to use a basic system to explore the *core* and *threshold* concepts as a methodical approach to curriculum review and reform.

Core concepts are those, which students really need to learn within a unit or course. Certain areas of the curriculum, however, appear more troubling than others for students. Meyer and Land have found that certain areas of curricula act like gateways – some students pass through and others do not (2003a, 2003b, 2006). They describe *threshold concepts* (TC) as 'akin to a portal, opening up a new and previously inaccessible way of thinking about something'. They discuss complex numbers as an example of something that is often considered absurd, even though it is a 'gateway' to approaches to understanding and solving problems in maths and science. Meyer and Land suggest that the threshold concepts are likely to be *transformative* i.e. that they mark a shift in the perception of the subject by the student, and *irreversible.* They suggest that where difficulties exist, the learners may be left in a state of *liminality* (Latin 'limen' - a threshold). Liminality may refer to an individual or a group - a suspended state in which understanding approximates to a kind of mimicry. The transition is problematic, troubling and often humbling, and students often mimic the new status without understanding the meaning of what they are doing. A very important aspect of curriculum reform will therefore consist of identifying threshold concepts, within the core concepts, so that ways of helping students pass through the threshold may be considered and built into the course structure. Very few engineering thresholds have been seriously researched to date (Meyer, et al., 2010). We are fortunate to have received an ALTC grant to support this work and to explore the fundamental thresholds to engineering learning, which will be discussed and debated with engineering academics across Australia and beyond. This knowledge will be fed directly into our curriculum and pedagogical development work.

Conclusion

The restructuring of courses at UWA has provided a rare opportunity to rethink and renew the way we educate engineers of the future. An extensive consultative process with stakeholders within and outside of the university has reinforced the need for greater focus on strong professional, interactive and problem solving skills alongside traditional technical skills. By adopting a multidisciplinary team-based approach to course design and delivery, along with effective pedagogical frameworks provided by recent engineering education research, the Faculty is developing exciting and challenging new courses to meet the needs of future Engineers.

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