Integrated Engineering – Implementation and Transition

Graham Town, Nic Tse, Byron Wilson, and Darren Bagnall
School of Engineering, Macquarie University, NSW 2109. Australia.
graham.town@mq.edu.au

C1: Integration of theory and practice in the learning and teaching process.

CONTEXT

Several approaches to improving the student experience and learning outcomes in engineering education have been proposed, including active learning (e.g. flipped classrooms), project-based learning, problem-based learning (PBL), peer-assisted learning (classroom or project-based), peer convening, etc. Some of these approaches have been shown to be very effective at motivating student learning, whilst also developing generic skills (e.g. communication, teamwork) and professional engineering skills (e.g. design, project management).

However, there are some trade-offs, e.g. the latter approaches are often either fragmented in their introduction, or are accompanied by a complete overhaul of the curriculum. It is also often not clear how to effectively mix different forms of pedagogy in an integrated curriculum, nor how to transition a curriculum to incorporate new forms of pedagogy without disruption.

PURPOSE

This paper proposes a curriculum framework with a significant proportion of problem-based and peer-assisted learning within an otherwise 'traditional' engineering curriculum. The aim of the framework is to provide a practical transition pathway for substantially increasing the proportion of project-based and peer-assisted learning into an established engineering program without major disruption.

APPROACH

The proposed framework is an extension of the 'Macquarie model' of engineering curriculum, in which core technical units sit around a spine of professional development units. The key innovation is the proposed restructuring of the program from a single spine to an array of "pillars", including a pillar of non-discipline-specific project-based units designed to develop both technical and professional competencies and facilitate peer-assisted learning between students with different specialisations or majors and at different stages of their studies. This will allow the introduction a substantial proportion of project-based and peer assisted learning, and future evolution of the curriculum with minimal disruption.

RESULTS

An integrated curriculum for undergraduate engineering education is proposed that we believe combines the best aspects of a 'traditional' engineering curriculum with project-based and peer-assisted approaches to learning, whilst also providing a practical pathway for transition to engaging methods of pedagogy within existing curriculum frameworks.

CONCLUSIONS

We propose an integrated model of engineering curriculum design based on 'pillars' that combines a range of learning approaches, linked as appropriate for the development of contextual and professional and technical knowledge and skills. The framework should also facilitate future evolution of the engineering curriculum, and the development of the broad range of competencies needed by modern engineers.

KEYWORDS

Curriculum, project-based learning, peer-assisted learning, multidisciplinary engineering.

Introduction

Instructional system design is a longstanding but nevertheless dynamic area of research. One of the drivers of change has been new technology (e.g. social media, computation and visualisation tools, virtual environments), which opens new ways for students to engage with their teachers, their peers, and the core knowledge and concepts with which they are expected to become familiar during their studies (Facer & Sandford, 2010). Other drivers include changing demands and expectations within the profession and broader society (Froyd, Wankat, & Smith, 2012).

A fundamental aspect of instructional design that continues to focus the attention of educators is the interrelationship between theory and practice in education, especially in the professional disciplines, such as engineering. Which comes first; theory or practice, understanding or competency? These are perennial questions which probably have no definitive answer – like wave-particle duality of light, it depends on the situation as to whether theory or practice may be more important, nevertheless both are equally necessary in engineering and their development should be integrated. (Alias, Lashari, Akasah, & Kesot, 2014)

To some extent the tension between theory and practice in engineering derives from how engineering has evolved over the last century or more, i.e. from a primarily practice-based 'art' learnt on the job, to one built on fundamental understandings of nature derived from mathematics and basic sciences. (Froyd et al., 2012) More recently, curriculum design and learning activities have evolved in response to an increased demand by stakeholders for the development of generic skills and attributes in graduates (including engineering), such as teamwork, communication, ability to self-learn, and also professional engineering skills and competencies (more specific to engineering), such as design, systems thinking, practical ability, project management, ethical behaviour and leadership (Moore & Voltmer, 2003). This has focused attention on approaches to developing both generic and professional engineering skills and competencies, at least within specific units (G. E. Town & Mcgill, 2008), and to the particular challenges in doing so in very large cohorts of students. (Schröder, Janßen, Leisten, Vossen, & Isenhardt, 2013)

A related and equally important question is then; how can we best structure a program of learning that properly balances the fundamental elements of engineering training, and furthermore, how best to implement such as program within the constraints of an existing curriculum framework and an evolving tertiary education system? A strategic framework of modern engineering education providing integrated development of relevant skills and knowledge has been proposed, based on three pillars of science, design and commercialisation (Quayle, 2010).

In this work we briefly review the approaches taken to date for integrating theory with practice, and technical with professional competencies in engineering curricula, and then propose a curriculum framework similar to that proposed by Quayle (Quayle, 2010), but instead integrating the following four 'pillars' in a 4-year engineering degree program;

i) specialist technical knowledge and skills,
ii) professional and generic skills,
iii) multi-year cross-disciplinary projects,
iv) contextual knowledge and electives outside engineering.

We believe the latter framework will facilitate a staged transition with minimal disruption from a 'traditional' engineering curriculum (Johnson, Ulseth, Smith, & Fox, 2015; Prasad, 2011) to a curriculum providing more balanced integration of theory with practice, technical with professional skills development, and specialist engineering with contextual knowledge, as has been argued is necessary to prepare future engineers for professional practice (Barakat, 2014; Buelin, J., Clark, A. C., Ernst, 2016; Cheville & Bunting, 2010; Director, Khosla, Rohrer, & Rutenbar, 1995; Pratley & Whitty, 2007; Quayle, 2010).

Furthermore, a broad-based engineering curriculum designed to train ‘Renaissance engineers’ will better prepare students for an ever-changing and increasingly complex world (Akay, 2003; Moore & Voltmer, 2003; Rainey, 2002) and is also likely to benefit society by attracting a wider diversity of students and preparing them for positions of responsibility.

Curriculum design

In learning, as in everything else we do, there is no doubt that *how* we learn has a large impact on *what* we learn, and that the best learning occurs when there is constructive alignment between learning outcomes, activities and assessment, as elucidated by Biggs (Biggs, 2012, 2014). The focus on the student and learning outcomes is consistent with systems approaches to education in designing learning programs (Godfrey, P.; Crick, R. Deakin; Huang, 2014; Rompelman & De Graaff, 2006).

It has long been recognised that engineering students require practical learning experiences, and consequently in most engineering programs i) laboratory classes are used to support the assimilation of theoretical concepts, ii) a ‘capstone’ project unit must be completed in which engineering skills are applied to a real problem, and iii) a minimum amount of industry experience must be accumulated before graduation. With some notable exceptions, the industry experience is usually not embedded in the curriculum, and often is not well managed, and hence the benefits are highly variable.

More generally, the links between content, process, and outcomes in learning have motivated the development of a variety of approaches to what may generally be described as ‘learning in action’, ranging in scope from the relatively narrow active learning in the classroom (Lage, M.J., Platt, G.J., Treglia, 2000; Zuber, 2016), to more wholistic approaches requiring deeper and more prolonged student engagement throughout entire units and programs of study (Biggs, 2012; Frank, Lavy, & Elata, 2003; Johnson et al., 2015; Kanigolla, 2013; Mills, J. E., and Treagust, 2003; Perrenet, Bouhuijs, & Smits, 2000; Prasad, 2011), including immersive engineering (Blashki, Nichol, Jia, & Prompramote, 2007).

The latter approaches aim to provide relatively open learning experiences which can integrate the development of technical, practical and professional competences. They can also assist learning by increasing student motivation, through projects with real and useful outcomes beyond the learning process, and possibly outside the formal learning environment, e.g. as in Engineers Without Borders (Wittig, 2013).

Taking the learning in action approach further and shifting to a completely project-based learning program would often require a complete overhaul of the engineering curriculum. The engineering program offered by Olin College is an early, notable, and successful example of this, in which the educators had substantial financial support and the rare opportunity to develop a largely project-based curriculum from the beginning with clear goals in mind (Guizzo, 2006; Somerville et al., 2005).

However, for a variety of reasons most engineering schools would find It difficult to undergo such a radical transformation, and would instead prefer to evolve their curricula and avoid major upheavals. Access to limited resources (e.g. learning spaces), dependence upon service units, university rules and regulations, may all work against radical curriculum changes. Which raises the question, is there a curriculum structure that would facilitate evolution, or continuous improvement of the curriculum, rather than a more radical approach to curriculum development?

Proposed Curriculum Framework

The curriculum framework shown in Figure 1 below is proposed to i) introduce a well-defined stream of problem and project-based learning into the curriculum, and ii) to reduce the amount of technical engineering content (i.e. from 90% to 75%) and add breadth by allowing an increased number of ‘non-engineering’ units, all with minimal disruption to existing programs.

Specifically, the changes are designed to introduce a new and structured PBL experience, and the benefits this mode of learning has been shown to bring, especially in engineering (Alias et al., 2014; Johnson et al., 2015; Mills, J. E., and Treagust, 2003; Perrenet et al., 2000; Somerville et al., 2005; Wittig, 2013). The framework is also intended to facilitate staged development of specific areas of competency (e.g. professional skills) throughout the 4 year engineering program.

Table 1: Proposed engineering curriculum based on 'pillars'

Foundation units 12.5% **+** **Minor units 12.5%** **+** **Context units 12.5%**	**Professional units 12.5%** Generic and professional skill development. *(Current 'spine')*	**PBL units 12.5%** Cross-year, multi-disciplinary projects. *(Proposed new 'pillar'.)*	**Technical units 12.5%** **+** **Technical major 12.5%** **+** **Final year project 12.5%**
MATH, PHYS COMP, etc.	**ENGG100** Generic	**ENGG150**	
MATH, PHYS, COMP, etc.	**ENGG200** Design	**ENGG250**	
ELECTIVES	**ENGG300** Research	**ENGG350**	
ELECTIVES	**ENGG400** Systems	**ENGG450**	

The above framework may be regarded as an extension of the 'Macquarie model' of engineering curriculum, in which a 'spine' of professional units (ENGG100 - ENGG400) runs throughout the 4 year program, the aim of which was and is to address a need for professional development content in a program which, at least initially, was heavily loaded with Science units. These units have been evolving end becoming more coherent over time, with the general aim to progressively develop a hierarchy of professional skills throughout the program, e.g. teamwork and communication (ENGG100 – ENGG400), design (ENGG200-ENGG400), self-learning (ENGG300 - ENGG400), and systems thinking (ENGG400).

The curriculum structure naturally lends itself to the introduction of a second 'spine' or 'pillar' of problem and project-based learning units (ENGG150-450), one per year. The introduction of a PBL-pillar will require a 10% reduction in the number of technical lecture-style units, however we believe this will be more than compensated by the benefits of engaging students in multi-year and multi-disciplinary project-based units, such as has recently been trialled (G. Town & Tse, 2016).

A similar curriculum model structured as 'pillars', was recently proposed by Quayle (Quayle, 2010), however in that case the pillars targeted distinct discipline areas (i.e. science, engineering design, and commercialisation, respectively). We have adopted a similar approach, but grouped skills development into pillars by type (practical, theoretical, technical, professional, etc.) in which the development of the associated skills and competencies can be more deliberately staged (as in ENGG100-ENGG400). Coordination between pillars would also be required in a properly integrated curriculum.

The advantages of the pillars, each extending throughout the 4 year program as shown schematically in Figure 1, are as follows;

i) allows introduction of a distinct 'pillar' of project-based learning activities engaging students across all 4 years in multidisciplinary projects,
ii) better accommodates a range of learning styles and interests by providing mix of classroom and project-based learning activities,
iii) sets aside clear space for broader contextual content (e.g. elective and minor units),
iv) provides a clear balance between technical and non-technical content, and between foundational science versus engineering content, etc.

Another advantage of the structure is that any pillar may be developed and revised from beginning to end without significant disruption to the other pillars in the program, facilitating coordinated and sustained development of the associated competencies.

Conclusion

An engineering curriculum framework has been proposed which incorporates distinct but connected streams (or pillars) focused on staged development of specific groups of competencies within an engineering program. The framework provides a number of advantages, including facilitating staged development and improvement of particular classes of skills (e.g. generic and technical), and the ability to overhaul or introduce new pillars into an established curriculum with minimal disruption (e.g. such as a dedicated project-based learning pillar). In a truly integrated curriculum the learning progress in each pillar would need to be coordinated, i.e. to utilise and reinforce the learning outcomes occurring in other pillars. The approach proposed here sees coordination across pillars as a secondary rather than primary task in curriculum design, and consequently is different to most current practice in which curricula are primarily built and structured around years of study.

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