Innovative Approaches to Engineering Education

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Summary

Innovation in engineering education ensures that degree programs attract students and transform them into graduates who are well prepared for future engineering practice that exploits new science and technology, and is responsive to changing socio-economic and environmental contexts. Drawing on examples from Australia and elsewhere, the paper outlines the rationale and implementation of several recent innovations in engineering education, and anticipates future directions.

During the past twenty years, university education has become more globalised, and has changed from being teacher-centered to learner-centered. Industry is ever more demanding of graduates' employability and value. In consequence, current degree programs more explicitly address the learning outcomes their graduates should attain. Typically, these cover discipline and contextual knowledge, practice knowledge and skills, and personal and professional attributes. Engineering, as a discipline, has led the development of graduate attribute specifications and adopted the educational principle of constructive alignment (of target outcomes, pedagogy and assessment) in curriculum unit design. Engineering operates international movements for accreditation and curriculum reform.

In-curriculum innovation includes increasing use of problem and project-based learning, group learning (and assessment) and threshold-concept learning, supported by engineering education research and staff development. Having good quality work integrated learning modules within engineering degrees enhances the authenticity of the curriculum with respect to industry practice. Innovative remote laboratories and other internet-delivered course material are encouraging more educators to share best practice, and 'flip' their classrooms to improve students' active learning. We envisage that MOOCs (massive open on-line courses) will progressively be adopted in engineering degrees, and will encourage more students into engineering.

Many reports on engineering have identified the diversity of professional pathways. An innovative educational response has been to encourage students' self-identity development, often through the notion of being a 'student engineer' rather than an 'engineering student'. Some institutions have introduced 'engineering leadership' for selected students, and there is perceived value in introducing business and entrepreneurial skills training. The need for such innovations partly reflects the fact that in many industrial countries engineering is not the first choice study area for many of the most able school leavers, and that engineering is largely invisible in the school curriculum. We conclude the paper by mentioning one innovative outreach program that takes engineering concepts and examples into secondary schools, enriching their students' educational experience and encouraging more to choose engineering as a future study pathway and career.

Abstract

Innovation is about doing useful things differently: converting novel ideas and methods into solutions that meet new needs, or adding significant value to established products and

services. In engineering education, new technological and practice requirements necessitate curriculum innovation, while innovation in educational practice can improve students' learning and faculty productivity. Most education innovation takes place within prescribed degree structures. This paper addresses the formative stage of professional engineering education: usually the bachelor degree of four or five years duration that is accredited by an external authority that represents the practicing profession.

The engineering profession in many countries has been constructively critical of its formative education, as the demands placed on the profession have increased and diversified. The most persistent general problem identified in the past two decades is that of authenticity: how can the university environment and curriculum focused on discipline-based engineering science and individual attainment adequately prepare graduates for engineering practice that is largely project and team based, and is often multi-disciplinary. This 'practice gap' has been exacerbated by most academics' research focus on engineering science, and their lack of engineering practice experience outside research. Related concerns have been a reduction of emphasis on engineering design, thus undermining graduates' preparation for a core engineering activity. Some reports have argued for broader and longer degree programs to address the tensions between generalization and specialization, and new and innovative programs have been created, including in Australia. The enduring challenge for most engineering education systems and providers is to resist packing more material into degree programs, and concentrate on delivering the range of attainable graduate outcomes. Sheppard and colleagues' recent publication [1] on how US engineering education needs to be transformed, and Graham's international study [2] on achieving change, have wide relevance.

In fact, engineering has been a leading university discipline in developing graduate attribute specifications, for both program accreditation and curriculum design. Typically, these are engineering-generic and cover knowledge, skills and personal attributes required to enter practice. National program accreditation assures stakeholders (employers, students, governments) of adequate graduate standards. Two international associations, with overlapping membership, have each agreed exemplar specifications of graduate attributes for benchmarking and mutual recognition of the graduates' qualifications that, in turn, support student and graduate mobility. Operating as the International Engineering Alliance (IEA), the Washington, Sydney and Dublin Accords have agreed specifications [3] for qualifications to enter the occupations of professional engineers, engineering technologist and engineering technicians, respectively. The Washington Accord has grown from six country signatories in 1989 to fifteen in 2012, with several further provisional and prospective members. In Europe, and consistent with the Bologna education process, the European Network for Accreditation of Engineering Education (ENAEE) authorizes national accreditation agencies to award the EUR-ACE label to first cycle (bachelor) and second cycle (master) degrees that meet the required specifications [4]. ENAEE currently has nine authorized country members, four of which are also signatories of the Washington Accord. Ongoing communication between the executives of IEA and ENAEE are facilitating harmonization and mutual understanding of their respective standards. .

A related international and innovative approach to the formulation and implementation of engineering curricula has been the CDIO (conceive-design-implement-operate) movement initiated by Massachusetts Institute of Technology and Sweden's Chalmers University and the Royal Institute of Technology. Realizing that their curricula over emphasized engineering science at the expense of preparing graduates for engineering practice, the architects of CDIO used the stages of the engineering process for curriculum specification and implementation, with increased attention to engineering design and practice. CDIO defines a generic engineering syllabus [5], and a set of standards for its implementation, that are broadly compatible with national and international accreditation standards. Now with 90 universities and affiliate members in all continents, CDIO provides a valuable open standard for contemporary global engineering education.

Accreditation and CDIO standards support, but do not guarantee, sound curriculum design and good student learning. The 'traditional' situation of university educators having little knowledge of educational principles, and 'teaching as they were taught', is becoming outmoded. Perhaps it is remarkable that it is considered innovative to require new (and experienced) educators to learn about and use best-practice educational techniques, as several universities now do. In Australia, specifically, the wider understanding of constructive alignment [6] has been instrumental in improving curriculum design and assessment at program and unit levels. Full professors of engineering education have been appointed and some countries, including Australia, have funding schemes to support innovation and quality improvement in university education. Engineering education research and publication is acquiring legitimacy through delivering improvements to education practice.

Three specific areas of curriculum innovation are currently transforming engineering education, and address aspects of the authenticity problem: problem-and project-based learning (PBL); group work, including self and peer assessment; and work integrated learning. While problems and capstone design and/or research projects have been used in engineering degrees for a long time, the innovation in PBL has been its systematic adoption at all program levels. For engineering, PBL in this form was pioneered at Aalborg University, and has been taken up elsewhere as a model for change [7]. Even in otherwise largely traditionally structured curricula, most Australian universities are using PBL in the first-year of their engineering programs to introduce students to engineering thinking, project work and teamwork and societal issues through the Engineers Without Borders Challenge (EWB) [8]. This has student groups address a development issue for a disadvantaged community in Australia or the region, with the EWB organization itself providing extensive resource materials. EWB, and the more technically intensive project framework of Formula SAE [9], are good examples of sharing good quality material and having student competition drive educational improvement, and emulate many aspects of professional engineering practice

Whilst students invariably enjoy such group projects, assessment of their collective and individual learning has been a challenging problem for faculty. However, research projects on group formation and self-and peer-assessment have led to sound guidance and supportive tools that, most critically, can increase students' self knowledge and capacity to reflect on their learning [10]. The value of work integrated learning in its many forms, such as internships, industry-derived projects and site visits, traditionally part of many engineering programs, is also being revisited. This is not without operational difficulties, as modern workplaces are less able to accommodate increasingly large cohorts of students. However, innovative technology, such as the immersive learning environment developed by Cameron and colleagues [11] is effectively bringing engineering plant and decision-making into the classroom, allowing students to understand the complexity of full-scale engineering design. A rich combination of project work and exposure to engineering practice throughout the curriculum provide excellent vehicles for students to develop their thinking and identity as 'student engineers' or 'engineers in training' [12]. Some universities, and accreditation systems, are encouraging students to keep a reflective journal in which they can chart their personal development against target graduate attributes.

Worldwide, engineering degrees are perceived to be difficult, requiring many abstract concepts to be mastered before gaining confidence in their fluent application. Academics are usually individuals who had less difficulty with theoretical understanding than their peers, so 'teaching as they were taught' misses the needs of many students. New evidence based theories in education, including 'threshold concept learning [13] are being adopted to improve learning. One key aspect of this theory is to present alternative approaches, and include relevant laboratory work, and software modeling simulation. Academics are being encouraged to provide students with guides to the ever-increasing internet-accessible range of relevant material, rather than create their own. Laboratory experiments remain important to demonstrate theoretical concepts and high quality internet-accessible laboratory experiments [14] are now available that allow students to do the required experiment when they want to, rather than on schedules that are often constrained by the equipment. There is evidence, too, that using well-designed MOOCs (massive open on-line course) material in campus-based course units can enrich individual students' learning, since they can pace themselves through the material and gain feedback through formative quizzes. These new educational approaches and tools are transforming and professionalizing the teaching dimension of the engineering academic role.

Innovation and intervention is needed to reach prospective engineering students while they are at school. Australia, USA, UK and other countries have shortages of engineers, and inadequate supply of school leavers motivated and qualified to study engineering. While school education rightly concentrates on mathematics and science as the pre-requisite subjects for engineering study, there are enormous opportunities for school science and mathematics to be enriched with examples from engineering. This happens through outreach programs that engage school students and support their teachers, initiated by engineering faculties and other organizations. One such example is the STELR (Science and Technology Education Leveraging Relevance) program [15] run by the Australian Academy of Technological Sciences and Engineering. This is a hands-on, inquiry-based, in-curriculum program designed for Year 9 or Year 10 students, on the theme of global warming and renewable energy. The program provides resources and teacher support for directed and student-designed practical investigations.

In conclusion, we believe that globally, engineering education and educators recognize the need for innovation. The educational and professional challenges faced are largely common between nations, and there are many national and international organizations and collaborations engaged on their solution. We have highlighted themes and examples of recent innovations, and we urge the global educational community to continue to share and adopt best practice as rapidly as their resources and systems permit.

References

[1] Sheppard S D, Macatangay, K Colby A & Sullivan W. *Educating Engineers: designing for the future of the field*. Carnegie Foundation for the Advancement of Teaching, Jossey-Bass, San Francisco, 2009.

[2] Graham R, *Achieving excellence in engineering education: the ingredients of successful change*. Royal Academy of Engineering. London, 2012.

[3] International Engineering Alliance. *Graduate Attributes and Professional Competencies, v2 2009*. http://www.washingtonaccord.org/IEA-Grad-Attr-Prof-Competencies-v2.pdf (viewed 21 Feb 2013).

[4] European Network for Accreditation of Engineering Education. http://www.enaee.eu/ (viewed 21 Feb 2013)

[5] Crawley E, Malmqvist J, Lucas, W, Brodeur, D. *The CDIO Syllabus v2.0. An Updated Statement of Goals for Engineering Education*. CDIO, 2012 http://www.cdio.org/framework-benefits/cdio-syllabus (viewed 21 Feb 2013)

[6] Biggs, J & Tang C, *Teaching for Quality Learning in University*, McGraw Hill International, New York 2011.

[7] De Graff E & Kolmos A (Eds), *Management of Change Implementation of Problem-Based Learning (PBL) and Project-Based Learning in Engineering*, Rotterdam:Sense Publications 2006

[8] Engineers Without Borders Challenge. http://www.ewb.org.au/whatwedo/institute/ewb-challenge (viewed 21 Feb 2013)

[9] Formula SAE. http://students.sae.org/competitions/formulaseries/about.htm (viewed 21 Feb 2013)

[10] Willey K & Gardner A.P. *Investigating the capacity of self and peer assessment activities to engage students and promote learning*. European Journal of Engineering Education, vol. 35, no. 4, pp. 429-443.

[11] Cameron I, Crosthwaite C, Shallcross D, Kavanagh J, Barton G, Maynard N, Tade M, & Hoadley A, *Development, deployment and educational assessment of advanced immersive learning environments for process engineering.* Office for Learning & Teaching, Australia 2009. Report accessed 21 Feb 2013 from http://www.olt.gov.au/resources/2142?text=cameron+

[12] Lindsay E, Munt R, Rogers H, Scott D, & Sullivan K. *Making students engineers*. Engineering Education: Journal of the Higher Education Academy Engineering Subject Centre, 3(2), UK, 2008.

[13] Land R, Smith J, & Meyer J. (Eds.). *Threshold concepts within the disciplines*. Rotterdam: Sense Publishers, 2008

[14] Azad K, Auer M & Harward J (eds.) *Internet Accessible Remote Laboratories: Scalable E-Learning Tools for Engineering and Science Disciplines,* IGI-Global 2012

[15] The STELR Project. Australian Academy of Technological Sciences and Engineering http://stelr.org.au/about-stelr/ (viewed 21 Feb 2013)