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Engineering the Curriculum

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Abstract: The pressures for change in the engineering curriculum have heightened in recent years. This paper explores some of the drivers for change, both in terms of the student population and also in terms of national and international policy moves, and explores some of the research - generic, STEM and engineering specific - that should underpin changes to the undergraduate engineering curriculum. It draws some conclusions from the research and suggests ideas for ways forward.

Introduction

Curricula need constant review and academics usually incorporate minor changes over a period of time. Occasionally, a more major review should be undertaken to assure the relevance, currency and quality of programmes. The need for a review of the engineering curriculum for the 21st century emanates from a number of sources, many of which impact on curricula across a wide range of disciplines:

- *Efficiency*. In straitened times the curriculum needs to be delivered as economically as possible whilst retaining standards. As programme enrolments grow, so does the need to maintain individual student contact.
- *Effectiveness*. With concerns about wastage rates, widening participation and student satisfaction, the curriculum needs to be designed to maximise student interest and motivation and, hence, to keep wastage to a minimum. Also, in present economic circumstances, employability skills become paramount for those graduating and entering the job market.
- *Efficacy*. In terms of student satisfaction, nationally, science and engineering subjects often fare less well than others. Whilst the methodology behind the National Student Survey might be questioned, it remains that engineering education does not entirely satisfy its students. This can impact on the quality of applicants.
- *The policy of the university*. Universities are struggling to differentiate their programmes and to balance the needs of the individual student with the need for mass education. In practice this appears to mean greater use of e-learning, but a focus on individual learning cannot be done without a concentration on student learning rather than on teaching.
- *The nature of the university*. In the UK, there has been an increasing national emphasis on links between research and teaching. In 'research-led' institutions, this means that teaching needs increasingly to recognise the emphasis of linking the learning to research activity; in those with a greater tradition of focus on teaching, this reinforces the need for more research and scholarship to underpin the student experience.
- *The nature of research*. Students entering doctoral research programmes are increasingly ill-prepared to undertake research degrees and their programmes of research skills often have to start from scratch.
- *The nature of the discipline*. Every discipline is dynamic and changes in subject knowledge need to be reflected in the curriculum. Small changes are made through the revision of individual modules and the ebb and flow of final-year options. However, there is a temptation to keep adding to the curriculum without a balancing pruning exercise and periodic review of the curriculum as a whole is necessary to reduce content inflation.

- *International re-appraisal of STEM education*. Engineering education, and STEM (Science, Technology, Engineering and Mathematics) education more widely, has come under particular scrutiny by professional bodies and government agencies in the UK, the US and Australia.
- *Internationalisation*. UK universities have long had a significant proportion of both students and staff from overseas, particularly in science and engineering. Moreover, there is an increasing emphasis on internationalisation, not only as a source of income but also because of the need to recognise the different background and needs of international students.

This paper sets out to look at the development of new engineering curricula in the light of current scholarship. This has involved a literature search as well as trying to establish details of best practice elsewhere. The list of references used is given at the end; some of these are specific to engineering or its particular branches, some to the wider STEM group of disciplines and others are generic. Views have been sought through contacts with Higher Education Academy Subject Centres and with professional bodies. The Higher Education Academy has commissioned a series of National Subject Profiles of which that relating to Materials is most relevant to engineering but that relating to Art, Design and Media may also have some relevance. The Physical Sciences Subject Centre has produced similar volumes for Chemistry and Physics.

Determinants

- *What is higher education for?* Charles Engel (Tomkinson, Engel and Warner: 2004) has perennially posed what he describes as 'the Ultimate Challenge'. This is predicated on the view that the world faces many serious challenges, many wicked problems, which cannot be tackled by traditional mono-disciplinary approaches. His view is that universities should equip graduates (including engineering graduates) with the skills to face the changes and challenges that global problems pose rather than narrow, and transient, disciplinary knowledge. In Australia, Robin King (2008) suggests that '… contemporary statements about the activities of professional engineers stress their roles in solving complex and relatively undefined problems, as well as the innovative and creative elements of the profession.'
- *Employability*. Rob Wilson (2009) suggests that the 'Business and other services' sector has the largest share of STEM graduates (excluding Medicine) and that this has been growing. However, he also sees growth in the 'Manufacturing' sector, which has so far seen a relatively small proportion of graduates. Mike Edmunds (2009) found differences of intention between Physics students in the last year of a three-year course and those in the last year of a four-year course, with many more of the latter looking for a career that would directly use their subject knowledge. Will Archer and Jess Davidson (2008) report that employers' top ten graduate attributes sought are:
    1. Communication skills
    2. Team-working skills
    3. Integrity
    4. Intellectual ability
    5. Confidence
    6. Character/personality
    7. Planning and organisational skills
    8. Literacy
    9. Numeracy
    10. Analysis & decision-making skills

  Attributes such as 'qualifications' and 'relevant course of study' are not only lower down the preference list, but also much more likely to be met by the graduates that they see. The largest gaps between what employers want and what they get are in 'Commercial awareness', Analysis and decision-making skills', 'Communication skills' and 'Literacy'. The first of these might be an unwarranted hope but the others are, surely, a reasonable expectation of a university graduate.

  The UK Centre for Materials Education (2008) suggests that Materials graduates have similar perceptions to their academic staff in the ranking of how well their degrees equipped them for the workplace - but at a significantly lower level. Those aspects which did better in the ranking tended to be the technical skills – IT, laboratory, technical report-writing – rather than the softer skills – ethics, career planning – or business skills – finance, entrepreneurship, legislation. In terms of relevance to the workplace, academic staff placed laboratory skills at the top, whereas graduates placed them 19 out of 25. Conversely, graduates placed high emphasis on enthusiasm, motivation and initiative, whereas these appeared much lower in the academic staff list.

- *e-Learning.* Online study is often seen as a panacea, both in satisfying student needs and also in providing an efficient means of delivery. The evidence that exists, on both counts, is rather less certain about this. Paul Bacsich and Charlotte Ash (2000) point to the difficulties of truly establishing the costs of 'networked' learning and Michael Gagan (2009) points to Chemistry students' perceptions of e-learning as being neither enjoyable nor effective. Physics students, according to Mike Edmunds (2009), find e-learning the least effective mode of teaching, but slightly more effective than do Chemistry students, and the majority of Physics students find it less than enjoyable. Elayne Clift (2009) also voices her disquiet about the effect that moving to more e-learning can have on academic staff. In response to this, Cameron Nichol (2009) suggests that 'Expecting a university lecturer, whose experience of teaching and learning is based on a traditional face to face lecture/tutorial model, to step in and teach online is like expecting your plumber to wire your house. It is a specialised skill and it requires a different approach to and an understanding of learning. Yes, it does take more time (and money) particularly to set up. To do the job the person has to let go of being a lecturer (and baggage that goes with it) and become a facilitator...'

  A recent meta-analysis conducted for the US Department of Education (Means et al: 2009) suggests there is evidence that online learning (and also blended learning) is more effective than face-to-face. However, the report does point to a number of limitations to this conclusion. First, in the online groups studied there was generally 'additional learning time and instructional elements not received by students in control conditions. This finding suggests that the positive effects associated with blended learning should not be attributed to the media, per se.' Second, the meta-analysis covers a range of groups from school-age to professional, though the majority of studies were at university or adult education level. Third, the studies used in the meta-analysis were largely self-reports by authors keen to demonstrate an improvement caused by their method of instruction '… many of the studies suffered from weaknesses such as small sample size; failure to report retention rates for students in the conditions being contrasted; and, in many cases, potential bias stemming from the authors' dual role as experimenters and instructors.' The other key feature is that those studies that demonstrated significant differences tended to feature a substantially restructured online programme rather than simply transferring the existing programme to a different medium.

- *Research-Teaching links.* A recent, unpublished, survey of early-career graduates, undertaken for the Royal Society of Chemistry (RSC) showed a perception that courses had proved inadequate to meet the demands of an early career in the skills areas, notably 'soft' skills - but had over-provided in terms of content. The emphasis sought here was one of equipping students with the skills to acquire, use and disseminate knowledge for themselves rather than simply learn 'facts'. Moreover, there were no significant differences in responses between employment sectors or, indeed, with PhD students. Despite the vast majority of graduates heading into employment, there are those who maintain that undergraduate courses should prepare students for a future academic career, through PhD studies: the evidence from the RSC study suggests that even this is not being done.

  Mick Healey and Alan Jenkins (2009) distinguish between research-tutored; research-based; research-led and research-oriented learning, with the latter two being essentially passive learning and the former two more active. Likewise, research-tutored and research-led learning are deemed to be more content-focussed: research-based and research-oriented learning more process-centred. That is not to say that any one mode is intrinsically preferable to another, rather that they might have a different application.

- *Widening participation, gender balance and ethnicity.* In a briefing for HEFCE [the Higher Education Funding Council for England], David Watson (2006) takes a philosophical, and somewhat sceptical, stance on the reasons for implementing widening participation and points to those who are increasingly left out of higher education. Nonetheless, he suggests that this is a long-term issue and that universities should not be pressed into short-term measures for implementation. He does suggest that there are many misconceptions but, despite them, there are also particular issues that non-traditional students bring, in particular in terms of parental expectations.

In looking at issues of widening participation, Mantz Yorke and Liz Thomas (2003) are critical of the basis on which data are obtained. They suggest that the postcode data that is usually used to determine under-represented groups is unreliable and may be inaccurate. Nonetheless, they suggest that factors likely to have an impact on the academic success of students from traditionally under-represented sectors of the population might include: a perception that the institution is 'friendly'; an emphasis on support before and during the first year of study; an emphasis on formative assessment in the early phases; a recognition of the social dimension of learning, and a preparedness to respond positively to the changing patterns of student engagement. Their study also relates to issues of wastage.

Susan Greenfield's report for the then Department of Trade and Industry (2002) suggests that the under-representation of women in science, engineering and technology significantly affects national competitiveness in the world. Whilst this issue is one that impacts greatly at school level and with women returning after career breaks (Royal Academy of Engineering: 2009) there is some evidence (National Academy of Engineering: 2008) that technical courses of study that include more of the transferable skills and 'softer' subjects (eg communication, ethics, design, leadership, sustainable development) tend to attract a higher proportion of female applicants.

- *Wastage rates.* Although focussing more on outcomes than on retention, a study by Sabine Severiens and Henk Schmidt (2009) suggests that institutions should look at how they adapt to incoming students rather than trying to help students to adapt to the institution. In advocating a student-centred approach, they also suggest that students who co-operate well with other students and feel at home in their institutions fare better academically. They cite Braxton and Lien as suggesting that this is also related to student departure decisions. Looking at academic and social integration as the route to achieving the adjustment of students, they conclude that problem-based learning [PBL] is a far more successful mode than either traditional approaches or a mixed mode. For more on PBL and the curriculum see Engel et al (2002). Nick Zepke and colleagues (2006), in a study across New Zealand universities, found that learner-centredness was paramount to retention - with a sense of belonging, with good quality teaching and support, and where diverse learning preferences are catered for.

- *Core curricula.* The concept of 'core curriculum' is a somewhat diffuse one and is often interpreted in different ways. The literature in this area is quite thin, possibly due to a lack of successful experiments, and mostly of a 'show and tell' variety. Ed Nuhfer (1999) refers to the problems of obtaining, and maintaining co-operation between participating departments as crucial to the success of inter-disciplinary ventures. More often, in this context, the concept is of an integrated engineering curriculum: Jeffrey Froyd and Matthew Ohland (2005) point to such curricula as largely being a first-year activity although the United States does have some 'Engineering Science' programmes that do not lead directly to professional accreditation. A more ambitious scheme (Olds, Middleton and Trefny: 1998) was devised at the Colorado School of Mines (CSM). This is still in operation, with some modification some ten years later. The CSM model includes first year studies of communication and ethics as well as basic mathematics and sciences. Design and systems thinking also feature strongly, and design forms a strand throughout the curriculum. The model also provides for a 'distributed core' that provides modules, particularly in technical subjects, common to several programmes but which do not feature in all. However, the prior educational experience of US undergraduates is very different from those in other parts of the world and care would need to be taken in transposing the model to other countries.

- *Other themes, identified from the literature.* One of the attributes of curriculum review more often put in as an afterthought than as an essential element is that of *assessment*. The prompt return of feedback to students, part of formative assessment, is seen as an essential ingredient of good teaching practice and also as a mechanism for supporting students from non-traditional and overseas backgrounds (Yorke: 2001). The constructive alignment approach (see eg Houghton: 2004) not only requires that assessment is aligned with learning outcomes but also that assessment is considered at the same time as learning outcomes are being formulated. Ruth Woodfield and colleagues (2005) suggest that there is little difference in performance, in different types of assessment, between male and female students. However, they found a preference for coursework assessment, rather than examinations, which is grounded in a belief that coursework is somehow a better measure of performance. Time-bounded written examinations can also pose difficulties for those whose first language is not English. Caroline Gipps (1999), in looking at secondary education, suggests that females, more than males, attend to the context in an assessment task and that means that attention must be given to context in the setting of assessments. Moreover, she suggests that a variety of different assessments is more likely to lead to equity in assessment.

  Beyond thoughts of aspects of the curriculum, thoughts must be focussed on the process of *managing change*. In the higher education context, change, particularly curriculum change, is seldom easy to achieve.

Conclusions and recommendations

Clearly, there are major drivers for engineering schools to undertake a radical revision of their curricula. The circumstances within each university, and within each faculty within the university, are unique but there is a telling body of evidence from around the world that gives some indicators on the directions for such a revision:

- The views of employers and graduates suggest that curricula in the sciences and engineering contain too much content that has to be regurgitated, rather than understood, and too little directed towards the skills that graduates actually need.
- Although there is some tentative evidence that students may produce better results if given well-considered and designed online support, students themselves do not appreciate this approach.
- Adopting a research-linked approach to teaching and learning can help develop many of the skills that students need without detracting from their learning of the subject and can help those who go on to postgraduate study.
- A broader range of student intake, with many from overseas or from non-traditional backgrounds, requires more sensitive approaches. Such students need to develop a sense of belonging early on in their academic life and may require additional support.
- Female students are largely under-represented in engineering disciplines. The evidence is that heightened attention to the skills base and incorporation of some of the ‘softer’ elements, eg Ethics, Sustainable Development, helps to attract female students.
- Students leave their programmes for a variety of reasons but there are a number of steps that can be taken to reduce wastage. The key elements are that curricula should be learner-centred and that good, prompt and frequent feedback is desirable. The social dimension of learning should not be overlooked.
- Some inter-disciplinary work, particularly in the early stages, can help with a number of the above points and enrich the learning experience. The idea of a ‘core curriculum’ that all students take has often proved unsuccessful, but there are instances where a range of engineering programmes have successfully followed an initial common curriculum.

An ideal revision should, therefore, be on the basis of a *research-inspired, learner-centred curriculum*, that includes professional studies to add breadth, enhance student employability and improve student motivation and retention. This implies significant research-oriented learning, although other more passive or content-rich learning may be appropriate to a more limited degree – for example staff briefly sharing their research ideas with new students. The curricula might include some online delivery but it is important that each thread of the curriculum be agreed before seeking the appropriate means of delivery. In the initial stages, at least, learning in groups should become a key feature.

Within Manchester some successful experimental changes have been made in a small way (see Tomkinson: 2009) and these have prompted further experimentation, but not on the scale necessary for wholesale curriculum change.

One suggestion is that universities offer a suite of course units which are available across the whole university. Whilst this suggestion might lead to some of the curriculum revisions sought, from the engineering viewpoint any 'broadening' units need to be incorporated in a cohesive manner, aligned to the curriculum and the particular context of the discipline, rather than in a 'pick and mix' fashion. However, the slavish adherence to a module with a fixed number of credits could run counter to the holistic approach suggested here. An interdisciplinary approach to some of the softer elements of the curriculum may be beneficial and should be incorporated if there is opportunity – this could, for example, give engineering students the experience of working with other professions.

A revised curriculum must take into account the specific needs of international students and those who are first-generation students. This implies a clear initial induction, and pre-induction, process that is linked to ongoing induction and support. Induction programmes need to be research oriented and might usefully be included at the start of every year; a second-year orientation would particularly help direct entrants to that year.

This brief review cannot set out the detail of the future curriculum; that needs to be done by small teams of academic staff within each university, given a brief to think brave thoughts. Initially these need to look at the broader issues and set parameters for the more detailed curriculum. One potential route forward is the use of Delphi techniques to collate ideas of best practice. This has been done in the context of sustainable development (Tomkinson et al: 2008).

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