Creating Tomorrow’s Engineering Designers

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ABSTRACT

In this paper, we identify serious shortcomings in the quality of current mechanical-engineering graduates from Australian universities. As a result, graduates exhibit a lack of understanding of: the basic sciences; engineering in the real world; and engineering professionalism. Whilst minor improvement can be achieved within current structures, we are convinced that only major restructuring, involving additional course length, changes in teaching methods, the availability of practitioners as teachers, and renewed emphasis on professionalism in engineering, exemplified through the creative design procedure, can begin the transformation from student towards what we have chosen to describe as a ‘complete engineer’.

INTRODUCTION

The Australian university system has experienced significant change over the past couple of decades, with general agreement among both academics and practitioners that much of this change has occurred because of pressure from the community. A university degree is now an expectation for a significant proportion of the population, and the resulting government policies are at least partly an attempt to contain the increased costs associated with higher student numbers and ever-increasing costs of educational technology. It is not too dramatic to claim that, as a result, universities have moved from the concept of a community of scholars to an organisation beset by cost cutting and reduced service delivery. Perhaps the best indicator is that students have become clients, and clients expect to receive, as their right, a tangible outcome from their contract with any university accepting them for undergraduate study. All this has occurred at a time of global change, with Australian design and industry under serious challenge, particularly from South-East Asia.

The main thrust of this paper is to document what we believe are very serious shortcomings, at least in undergraduate mechanical-engineering education, which have arisen as a result of the aforementioned societal and governmental changes, combined with an increase in the body of engineering knowledge and the effects of an increasing level of technology.

I. RATIONALE

The authors of this paper are a group of mechanical engineers, working within industry and academia, who have serious concern regarding the quality of mechanical engineers graduating from the current university system. Two of our number run successful design consultancies employing fresh or recent graduates, one ran a large design office as part of a large manufacturing enterprise, two others have very extensive and ongoing design experience in industry, six have majored in mechanical-engineering design teaching at university level whilst maintaining strong industry links, and three are active in part-time teaching/tutoring in engineering design. All are or have been members of Engineers Australia’s National Committee on Engineering Design but wish to make it clear that the opinions expressed in this paper are our own, are not those of Engineers Australia, and are not necessarily those of the universities with which we are associated.

We acknowledge that some of our views may be at variance with the outcomes of formal university, teaching-staff, or student surveys, but question the suitability of such surveys for identifying practitioner or industry views. We have not attempted to survey outside our own group, and depend on the weight of opinion and evidence from a group of highly experienced teachers and employers of recent graduates, scattered over four Australian states and with teaching links to eight Australian universities.

Our paper is not intended to be a criticism of the many who have laboured long and diligently over past decades within Australian engineering education, but rather an attempt to focus attention on the serious cumulative effects of the pressures and enforced changes over that period.
II. DEFINITION

We define a professional engineer as a person who, by a combination of innate ability, motivation and a rigorous, structured course of study, understands how the world works and is equipped to change that world for the benefit of humankind.

Although the word ‘design’ does not appear in our definition, it is clear that the phrase ‘change the world for the benefit of humankind’ can only be brought about by the implementation of creative design. In fact, we see creative design as both the integrator and the end point of engineering endeavour. Whilst we recognise that only a small proportion of engineers will spend their working lives as ‘designers’, we maintain that it is the ability to apply the ‘design’ approach to problem solving that distinguishes a professional engineer. It is within the area of ‘design’ that the shortcomings of current university courses are most clearly displayed and the need for change is greatest. For that reason, the focus of this paper is on creating tomorrow’s engineering designers.

III. THE CURRENT COURSE

A. Student Intake

The first step in creating professional engineers must be to attract candidates having the required innate ability combined with a motivation to build a career as a professional engineer. We believe the shortcomings of the current system begin at this point.

When universities or faculties under-enrol, they suffer financial penalties. We understand that the admission levels are set and, if necessary, readjusted to fill a particular university’s student quota for the course. We see two main problems with this system: in many universities a proportion of the intake comprises students who lack a sound academic foundation, either through doubtful academic ability or poor choice of subjects at secondary school; and societal pressures expect sons and daughters to get a degree, leading to ‘I’m here because I couldn’t get into (or didn’t want to do) anything else’. Some universities run bridging courses in the basic sciences to compensate for their students’ inadequate preparation, and this may be of benefit in enrolling motivated students who made unfortunate choices in secondary school. Nevertheless, we estimate that, in many cases, lecturers are left with a class in which one-third or more of the student cohort is inadequately prepared, of marginal ability and, perhaps even worse, lacking motivation to achieve an understanding of the principles being presented. The result is that, to achieve an ‘acceptable’ pass rate according to government (and hence university) ‘guidelines’, academic standards begin to drop in first year, an effect which is cumulative as the course progresses.

B. Course Content

Professional mechanical-engineering courses remain almost universally of four-year duration and inevitably begin at the level of Newton’s Laws. In past decades, the basic sciences plus subjects such as engineering drawing were studied at high school and were topped up, or at least given an engineering focus, in first-year university. That this is no longer the case has been recognised for some time. Criticism of engineering courses has also come from outside the ranks of engineers. We are aware of one review which included academics from a Science Faculty and concluded that engineers could no longer be regarded as having the same status as scientists, due to inadequate knowledge of the basic sciences (unpublished). A similar theme is expressed in a review (Australian Academy of Science, 2006) explaining the decreased emphasis on mathematics and statistics in Australian universities and, at the time of writing (January/February 2007), the perceived shortcomings of university courses have been a major topic of discussion in, for example, the opinion pages of a leading Sydney newspaper (Sydney Morning Herald, 2007).

Also, over the years, the body of engineering knowledge has increased almost exponentially, and universities continue to cram what is regarded as essential new engineering-science material into the same four-year course. Additionally, course time must now be devoted to teaching aspects of management and engineering ethics and environmental issues, all of which are required for compliance with Engineers-Australia criteria for course accreditation.

The result is a course from which the basic sciences have been reduced or dropped (except for mathematics, which has, in some instances, been increased), yet remains so crowded that there is little opportunity for lecturers to present course material in a way which fosters understanding, and little incentive for students to develop their understanding of the engineering principles being taught. It is our thesis that development of understanding as the course proceeds, subject by subject, is an essential foundation for creating a professional engineer. By contrast, our classroom experience strongly suggests that many students have developed the belief that they can become professional engineers merely by regurgitating 50% of their course notes or pre-worked problems twice a year. Hence, for the better students, the class environment is stultifying and the problems inevitably become worse as students lacking understanding are allowed to progress to the later years of the course.

C. Staffing

The effects of funding pressures are particularly evident in the selection of academic staff to teach engineering design. Teaching design has in fact been a source of difficulty for many university administrators for many years. A good design teacher must be a practitioner, with the rare gift of ‘doing’ rather than ‘telling how’. This gift will in most cases result in an ongoing involvement with industry, but the resulting products are more likely to be subject to commercial secrecy agreements than to fit the traditional university expectation of a published paper. Further, any design activity is time consuming, for students and teachers alike, and will be difficult to assess, providing further excuses for reducing design subjects to a minimum.

We have for some years been aware of a tendency for universities to appoint design-teaching staff more on their ability and willingness to contribute to a school’s research
specialisation than on demonstrated design ability (Churches and Magin, 2001). We do not decry the calibre of such staff, but are adamant that their experience (and, often, interest) does not equip them for the task. In some cases, the appointee has gone through that school’s undergraduate course, moved on to a PhD in the same school and is appointed to teach design solely on the basis of design experience in his/her undergraduate course. In such cases, there must be a strong incentive to ‘teach from the textbook’. A critical evaluation of most textbooks with ‘Engineering Design’ in their title shows that they are strong on analysis of machine elements (or systems, or whatever) but weak to the point of non-existence in actual design content. For an inexperienced teacher, setting a creative design exercise is to be avoided since it might cause embarrassment if he/she were asked by students to provide ‘the solution’, or even ‘a solution’. In this respect, it is instructive to compare current teachers of engineering design with instructors of students learning clinical medicine.

IV. THE CURRENT PRODUCT

We accept that some students will achieve engineering brilliance despite shortcomings of current courses, but in this paper it is appropriate to focus on the standard achieved by the rank and file of our engineering graduates.

Three of our authors recruit or have recruited new or recent graduates in their design consultancy or design office. All have expressed concern at the lack of understanding of the material world shown by job applicants. One consultancy has developed a series of ‘understanding’ questions in which typical undergraduate course material is placed in a practical context, for example: which way would you place an I-beam to carry a bending load; why do gas cylinders have domed ends; what keeps the pendulum moving in a grandfather clock and what makes the ticking noise. The answers starkly highlight the shortcomings of current graduates.

V. WHAT IS NEEDED?

We do not suggest that it is possible for universities to graduate engineers who are equipped with the knowledge required for the rest of their career. Indeed, one of the foundation stones of an undergraduate course in a rapidly evolving profession must be an ability for self-learning and self-learning can only be built on a thorough understanding of basic engineering principles and knowledge, where ‘understanding’ is the key word. Nor do we imply that extensive engineering experience can somehow be squeezed into an undergraduate (or even graduate) degree. Nevertheless, in our view it is necessary for an engineering graduate to have moved at least some way towards the status of professional engineer, where the crucial step in the transformation is the development of skill in real-world problem solving. This step is best exemplified and taught through the design process or design methodology – embodying the art as well as the skill of design synthesis and its melding with analytical ability to create an engineering designer, capable of extrapolation beyond the boundaries of current knowledge and technology. The archaic phrase ‘complet engineer’, with all its connotations, is an excellent descriptor of what we are trying to achieve.

We observe that if this phase exists at all in current Australian undergraduate courses, its prevalence is declining as senior design teachers retire. Of course, only a few graduates will turn out to be full-time designers, but all need to be able to apply the design process to all their professional work:

- be sure to solve the right problem, not necessarily the one articulated;
- see your first solution as no more than a stepping-stone to better solutions;
- know what technology is available; and
- be prepared to justify your decisions and choices.

VI. POSSIBLE WAYS FORWARD

In view of the multi-factorial nature of the course shortcomings, there can be no simple ‘fix’ and effective proposals will involve cost, to the student as well as to the university funding system. The appropriate changes may well vary from university to university, although we would expect much common ground.

A. The Student Cohort

There are some prospects of attracting a better prepared and better motivated student cohort within the next few years. The Australian Government and the engineering profession are currently encouraging an increase in student interest in the sciences at secondary-school level. There is also a renewed focus within both primary and secondary education on design, engineering and science. We suggest closer liaison with secondary schools, particularly those which have already demonstrated significant achievements in teaching design and technology, in order to attract more committed students. However, a better student cohort cannot of itself bring about the changes we believe are essential. There must also be changes in course format, course content and teaching procedures.

B. Course Content

In our opinion, a major difficulty to be addressed is the grossly excessive material crammed into current courses, leading to an emphasis on passing examinations, rather than acquiring understanding of engineering principles.

We are aware of course presentations where valiant efforts are made to teach in a way which encourages student understanding, and we have no doubt that, in general, more could be done within current course structures. Nevertheless, it is our opinion that, in practical terms, significantly more course time is essential if the rank and file of students are to be encouraged to understand basic engineering principles and how they apply to the material world. This implies a degree of at least five years.

Our preferred proposal is for a two-stage degree comprising, say, a three-year para-professional ‘B Tech’ or

* The European ‘Ingenieur’ has much in common with our concept.
similarly named qualification, with a strong focus on basic science and basic engineering principles, including engineering design, and an insistence on a demonstration of understanding, in order to achieve a pass. Whilst students whose performance was deemed to be marginal (or perhaps less than 'credit' grading) would not be permitted to proceed (at least not immediately) beyond the three-year degree, this might offer an honourable way out, with a reasonable qualification (e.g. as Engineering Technologist), to a significant proportion of the student intake.

Students deemed to have both ability and motivation could then embark on a further one-, two- or three-year course leading to alternative engineering specialisations (including business, technology, research) and a fully professional qualification. The focus in the professional course would be on the more advanced engineering sciences (with some specialisation), ethical and environmental considerations, plus a strong emphasis on achieving professionalism through the integrating factor of the creative engineering design process – its art as well as its science. Reduced student numbers, improved student ability, and more highly motivated students would transform the class environment. The possibility of economy of scale, achieved by running only one such course in each major city, might be considered.

We note that the proposed ‘Melbourne Model’ to be phased in from 2008 (University of Melbourne, 2007) has a similar ‘3+2’ academic structure, so we are confident that our proposal has a realistic format. We are, however, sceptical that the BSc-ME plan for UoM will be able to accommodate a full semester’s worth of professional (design) engineering content and still satisfy that university’s philosophy for a broad-based foundation degree. There is also some doubt about the likelihood of accommodating both professional and research-focused Masters’ courses at UoM, but we are confident that specialist Masters’ courses could be developed for articulation at other universities.

C. Staffing

In considering any restructure, the question of staffing needs careful consideration. The presence of at least one specialist practising designer is an essential part of the equation, together with existing specialists in the various engineering sciences. Part-time ‘project leaders’ or tutors from industry can be a valuable resource, but full-time design staff are essential for course planning and continuity as well as day-to-day management of student support. An ideal solution would be a one-year (or even one-session) commitment by an acknowledged designer from industry to act as a designer-in-residence, generating a suitable project and guiding it through to completion. Such a solution is not without cost, but does bring its own rewards to all participants.

We are convinced that, in the early twenty-first century, Australian industry (with a few notable exceptions) lacks the ability, facilities and will to transform the student into a ‘complete engineer’. It follows that universities must be responsible for at least the initial steps in this process. One way may be for universities to help develop suitable staff by offering scholarships towards a professional doctorate for suitably qualified designers from industry.

VII. Conclusion

The main thrust of this paper has been to draw attention to the unsatisfactory nature of current mechanical-engineering courses in Australia, their unsuitability for professional engineers in the twenty-first century, and the ramifications of their shortcomings at a time when the future of Australian mechanical engineering is under challenge from South-East Asia.

We believe there is no simple ‘quick fix’. The remedy will be costly for both student and university, involving additional course time and major changes to teaching methods in order to promote understanding of engineering in the real world and to begin the process of transforming the student to ‘complete engineer’.

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REFERENCES


