AAEE 2012 CONFERENCE
Melbourne, Australia
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Why Do Attempts at Engineering Education Reform Consistently Fall Short?

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BACKGROUND

Reformers have proposed improvements in engineering education for several decades yet there have been few conceptual advances in the curriculum since it became largely based on engineering science in the 1960s. In contrast, an overwhelming increase in the number of students facing academics in lecture theatres has swamped small curriculum changes. Explanations for curriculum reform failures have mostly relied on the apparent reluctance of engineering academics to change pedagogy or engage with industrial practice. However, another possibility is that the arguments for reform have fallen short, lacking a secure philosophical grounding.

PURPOSE

This paper argues that engineering education reform must necessarily be based on a widely appreciated understanding of engineering practice, and how improvements in graduate capabilities would, in turn, improve practice, yielding net social and economic benefits. Second, the paper argues that prevailing understandings of engineering practice are inadequate, and that there is only a limited understanding on how engineering creates social benefits.

DESIGN/METHOD

The argument is based on previously published research on engineering practice, attitudes of engineering faculty, and engineering education reform. Content analysis of a representative sample of engineering texts provides additional data on prevailing understandings of practice and how engineering creates social benefits.

RESULTS

By focusing on one aspect of engineering practice, communication, the paper shows why prevailing understandings of engineering practice can be questioned, and that understandings on education costs and value creation are tenuous.

CONCLUSIONS

The implication of this paper is that contemporary efforts to reform engineering education lack secure intellectual foundations. Without an accurate and widely appreciated understanding of engineering practice, and an understanding on how engineering creates social benefits, an argument to reform engineering education may have only weak validity and this might explain why reforms tend to be rejected.

KEYWORDS

Engineering education, engineering practice, curriculum reform.

Introduction

There have been many calls to transform engineering education. Some have come from a utilitarian perspective, resting on assumptions that education transformations can improve economic development. In Australia, for example, shortages of skilled engineers reported by companies have prompted calls for more students to study science, technology and engineering studies, more education funding and also efforts to reduce the attrition rates in engineering degree courses (King, 2008). Recent British reports have pointed to lack of appropriate "practical" and communication skills in engineering graduates (Royal Academy of Engineering, 2010; Spinks, Silburn, & Birchall, 2006).

Other reports have pointed to future challenges such as climate change, resource shortages, rising population, and the need to live within the earth's capacity to support human civilization (Duderstadt, 2008; National Academy of Engineering, 2004, 2005). They argued that overcoming these challenges will require engineers with skills distinctly different from those of today's engineers.

Transformation of university education pedagogy has also been advocated, for instance, by the Boyer Commission Report (1998). Others have advocated strongly for retaining the humanities in education programs. Some American reports also reflect a desire to maintain world economic leadership and, by implication, a contemporary national advantage.

Most proposals contain implicit assumptions about engineering in practice beyond the academy. In particular, there is an assumption that education transformation can significantly influence our ability to "do engineering" as a powerful means to secure economic prosperity, social justice, and sustainable development objectives. Therefore, by implication, each transformation proposal contains presumptions that the education requirements to prepare graduates for professional practice are clearly understood. Each proposal also, by implication, rests on presumptions about how social benefits emerge from engineering practice.

We can represent these three presumptions symbolically.

A. Education → Graduate Attributes: the presumption that we know how to adjust education in order to enable students to acquire desirable attributes by the time they graduate.
B. Graduate Attributes → Engineering Practice: the presumption that we know the influence of graduate attributes on engineering practice, and hence which attributes are relevant and if so, whether essential or desirable.
C. Engineering Practice → Social Benefits: the presumption that we know how engineering practice results in desirable net social benefits, and how this will happen in future.

For example, in some reform proposals there are findings that suggest certain skills, such as communication abilities, will enhance the performance of graduate engineers. Earlier proposals for education transformation, of course, stimulated changes in accreditation criteria that appeared at the turn of the century, and the well-known list of 11 ABET program outcomes at the heart of EC2000 represented a compact description of the skills and knowledge required to commence the practice of engineering (Lattuca, Terenzini, & Volkwein, 2006). The brief program outcome descriptions, each with 10-15 words, reflected notions of individual behavioural competencies as a way to describe the human attributes needed to perform a particular kind of work. Engineers Australia adopted a similar approach specified in more detail (Engineers Australia, 2011). However, as Shippmann *et al* (2000, p. 735) have pointed out, competency descriptions require a deep and intimate understanding of the workplace if they are to be interpreted accurately, and "leave a large portion of what is related to an individual's success in a job unaccounted for". The act of writing such program outcomes implies that presumptions A, B and C described above were thought to be valid at the time.

Research reports on engineering practice are scarce and difficult to find. They are so scarce that Barley (2005) was able to point to a near complete lack of understanding about technical work, at least from a research perspective. Of course, the absence of systematic research on what engineers actually do does not, by itself, imply that our understandings about technical work are (or have been) incorrect. However, several research studies have appeared since 2005, and there are now sufficient findings to reassess earlier understandings of engineering practice, and hence presumptions B and C. The findings indicate fundamental differences between the realities of engineering practice and the understandings held by engineering faculty, many of whom have contributed to recent calls for education transformation.

Educators' notions of engineering practice

Engineers are people for whom their primary occupational identity is based on knowledge associated with engineering schools and allied communities of practice. This causes difficulties for many practicing engineers who report (in both casual conversations and research interviews) that they hardly do any 'real engineering' in their work. For them, 'real engineering' is what they learned in engineering schools and it still provides their primary link to the engineering profession.

For engineering educators their engineering identity is important because it distinguishes them from the other physical science disciplines. In leading contemporary engineering schools there is often an overwhelming representation of engineering technology and science researchers among the faculty: the result of university recruitment and promotion practices. Quinlan's (2002) observation that many faculty see engineering in terms of "scientific process of developing new theories from which the viability of new designs can be tested" reflects the research identity that characterizes these schools. In other words, engineering faculty subscribe to a generalized view of engineering expressed in terms of the engineering that they practice themselves. She also described how 'design division' faculty saw engineering as a creative discipline through which new products are developed. These different views shaped their teaching, disputes on education priorities, and hence the experiences of students in their classes.

Sheppard and her colleagues (2006) provided further insights in a study that explored perceptions of about 300 faculty and students based on semi-structured interviews and focus groups in seven major American universities. These perceptions centred on problem solving based on expert theoretical and contextual knowledge, supported by a combination of formal processes and creativity.

Pawley (2009) found that engineering faculty valued different ideas and conclusions and that calls to reshape the discipline were unlikely to influence their teaching (p309). She perceived three 'universalized disciplinary narratives': engineering as applied science and mathematics, engineering as solving problems, and engineering as making things. She questioned whether calls to "Change the Conversation" about engineering (National Academy of Engineering, 2008) would have any impact unless faculty share the messages with students and model new behaviours. Williams (2003) distinguished three diverging movements within academies: engineering science, design, and management systems, the latter two nourished from pragmatic commercial interests. She argued that historical and technological developments have led to an identity crisis in engineering and, as a result, education has become a 'contested domain.'

In the ethnographies by Stevens and his colleagues looking at engineering educators (2008), and by Tonso looking at student teams (2006), we can see how engineering education shapes the 'accountable disciplinary knowledge', skills, values attitudes and identities as students grow into "engineering". Educators assume the responsibility for appropriately shaping this developmental process, and their notions of engineering practice can have a profound effect on their students' beliefs.

Difficulties arise, however, for the majority of their graduates who emerge from university or college and practice in a different setting. When graduates experience engineering as practiced in most industries other than research and education, they can feel disoriented. "*When I started, I felt completely unable to do anything useful*," one graduate reported to the author recently. Martin and her colleagues (2005) described how graduates found they were not well prepared to work with other people and lacked practical skills, factors widely reported in many other similar studies (e.g. Spinks, Silburn, & Birchall, 2007). In Australia, most companies assert that it takes 3-5 years for a novice engineer to become reasonably productive in a commercial context. The transition into industrial practice can be discomforting for many novices and employers alike. Many Australian employers have expressed their dissatisfaction with the capabilities of graduate engineers and prefer to recruit engineers with five or more years of experience if they can find them.

A university education needs to take students beyond the skills requirements of a particular profession, such as engineering. Bowden and Marton (1998), for example, have argued strongly that we need to prepare our graduates to confront challenges outside the experience of today's engineers and academics. Their work was based on a variety of higher education learning research studies. At the same time, most educators would like their students to experience a successful start in their chosen careers.

Medical educators have embraced extensive clinical practice and situate themselves in, or close to teaching hospitals to promote the successful transfer of academic learning to practice. In the last two or three years of formal education, most teaching is conducted by staff with extensive current practice experience. Engineering educators have to prepare their students for a much greater diversity of career settings, and real engineering settings often require secrecy or are too large, too expensive or too hazardous to accommodate within a teaching institution. Perhaps because of this, the impracticality of bringing engineering practice into the academy, notions of practice held by the academy have diverged far from the reality encountered by graduates, as demonstrated later in this paper. Few engineering educators have industry experience that reflects a broad range of practice (Cameron, Reidsema, & Hadgraft, 2011).

While the importance of professional skills and the socio-technical nature of problem solving in the workplace have been acknowledged in research literature (e.g. Jonassen, Strobel, & Lee, 2006; Korte, Sheppard, & Jordan, 2008; Sheppard, Macatangay, Colby, & Sullivan, 2009), these aspects still occupy the curricular margins (Downey, 2009). This is partly because professional skills are mostly described in terms of 'generic, non-technical capabilities'. Building students' capacity for solitary technical problem-solving remains the central objective of engineering education.

Contemporary understandings of communication in engineering practice

In order to draw some comparisons with research findings, however, we need to look in more detail at particular aspects of practice. In this paper, there is only sufficient space to discuss one, the significance of communication in engineering practice.

One effective way to understand concepts of practice prevalent in 'the academy' is to analyse texts that attempt to describe engineering practice for students, and also detailed texts that prescribe education for engineers. Content analysis (Walter, 2006) based on 16 representative texts that introduce engineering, engineering practice or prescribe engineering education (listed at the end of this paper) revealed a contemporary discourse in engineering education that frames communication as information transfer, almost always as a monologue in which an engineer writes or speaks to others, supported by graphics or artefacts. Very few of the many communication genres observed in practice were mentioned the texts. Even highly experienced engineers with extensive commercial practice see communication as information transfer (e.g. Galloway, 2008, p. p26). Curriculum mostly addresses communication in three ways:

- Written technical reports, culminating in a capstone project report or thesis, and
- Technical explanations, usually assessed in the form of a formal presentation, supplemented by artefacts or graphics,
- Team work, in which students work together in small groups to perform laboratory tasks, projects that may involve construction of artefacts, and assignments performed by several students who submit a single report. While students receive extensive support for report writing, communication required for teamwork is seldom if ever taught (Sheppard, et al., 2009, p67).

Even within these curriculum segments, communication abilities seldom form a large component of assessment: it would be unusual for less than 70% of assessment to be based on technical content. If communication skills are explicitly taught, often under the heading of "professional skill development", instruction is often delegated to specialist communication teachers (e.g. Paretti, 2008) towards whom engineering students can display resistance. Students identify technical specialists as "the real engineers". As a result, communication development is seen as an add-on, a "tick the box" requirement rather than part of the mainstream curriculum.

Naturally, one can argue that communication is unavoidable in education. For example, nearly all assessment also relies on communication abilities, usually writing. Nevertheless, students see the communication component of engineering as a subsidiary postscript performed after the 'real engineering' is done. The postscript, while not unimportant, requires an engineer to communicate the 'problem' solution, *informing* 'the client', transferring the information to the client representing the problem solution by means of a technical report or presentation. This in turn reinforces, and is reinforced by the traditional teacher-centred model of instruction in which academics convey the discipline to students listening in lectures.

Engineering practice research findings

Research studies on engineering practice, however, have provided quite different insights on engineers' communication.

In stark contrast with student expectations, several research studies in a variety of settings confirm that engineers, on average, spend 60% of their time on direct communication with other people. Two independent studies have demonstrated that novice engineers spend just as much time communicating as more experienced engineers (Trevelyan, 2010). Instead of being a mere postscript, communication dominates practice, even for novices.

Faulkner (2007) described a series of complex socio-technical performances that characterize engineering. She reported an engineer describing it this way: "*It's all engineering really – all nuts and bolts,* then he paused for a minute and added, as if to correct himself, *Well, nuts and bolts and people.*" Faulkner described how engineers deploy a repertoire of skills, handing delicate interpersonal situations, project management, accounting, line management, teambuilding and the ability to build and maintain network of contacts. Korte (2008) described early career engineers learning how industrial problem-solving relies more on securing the help of people with the required know-how than the analytical approaches learned in university studies. Trevelyan (2007) described technical coordination as the "predominant" aspect of practice in which engineers gain the willing and conscientious collaboration of many others without relying on pre-existing organizational or social authority. He later described engineering as a "human performance" that relies on distributed expertise in which the core technical knowledge used by engineers originates from social interactions because no single person can carry sufficient knowledge by themselves (2010). Trevelyan's results have been supported by similar findings from US and other settings (Anderson, Courter, McGlamery, Nathans-Kelly, & Nicometo, 2010; Larsson, 2007; Tang, 2012).

Trevelyan (2010) described how engineers relegate social and relational work to a subsidiary “non-engineering” status, preferring to describe it in vague technical terms such as “technical qualification” or “software upgrade work”. Even though they appreciate its critical importance, it can take persistent probing for these engineers to reveal the underlying social nature of their technical work. Some engineers even describe a feeling of guilt that emerges in their language: *“I have to confess I do very little purely technical work these days. It’s not what I was trained for, it seems I am only pretending to be an engineer.”* These patterns of social interaction and its relegation in engineers’ discourse are not obvious even to practitioners. Trevelyan and his colleagues have reported that none of their participants described them explicitly. Instead, they emerged as a result of qualitative analysis of interview transcripts and field observations.

The research findings, therefore, demonstrate that concepts of communication held widely in academic circles do not adequately represent the realities of communication in engineering practice. The validity of presumption B, therefore, has to be questioned.

Understandings on costs and value creation

Interestingly, the cost of engineering education has not been discussed much at all in the engineering education research literature, in contrast with extensive arguments on the relative effectiveness of different education approaches (Trevelyan, 2011).

Value creation from education, even from engineering itself also seems to have received little attention. There are few explicit discussions on social and economic value creation. Instead, there are implicit assumptions that innovation and the development of new technology is intrinsically valuable. Content analysis of the same set of texts revealed only two cursory references to an 1877 description of engineering as “the art of doing (construction) well with one dollar which any bungler can do with two, after a fashion.” (Wellington, 1887). Trevelyan (2012) has demonstrated that most practicing engineers have great difficulty explaining the value of their work, possibly because texts do not address this.

In other words, there is no longer a widely appreciated understanding among engineers and educators on the costs of engineering education, nor how engineering produces social and economic benefits. Therefore, the validity of presumption C also needs to be questioned.

Conclusions and Implications

Returning to the presumptions A, B and C listed in the introduction, the evidence presented in this paper casts doubt on the validity of presumptions B and C. Widely held notions of engineering practice among engineering faculty do not reflect the realities of most engineering practice as revealed by research studies. (While evidence was only presented for an aspect of communication, other research demonstrates similar divergence on more than 40 other aspects of practice.) Further, there do not appear to be explicitly articulated understandings about the ways that the social and economic benefits of engineering practice outweigh the costs, neither among engineering academics nor practising engineers.

Therefore, irrespective of the validity of presumption A, the necessary foundations for a rigorous argument to reform engineering education now appear to be questionable. This might help to explain why calls for reform seem to have fallen on deaf ears among many (but not all) engineering faculty staff.

The main implication is that education reform attempts may be accepted more readily if there were a more extensive and widely disseminated body of research on engineering practice and how it creates social and economic value, and how graduate attributes influence practice. We also need to understand the social and economic costs of different aspects of engineering education, both formal classroom education and informal workplace learning.

List of Engineering Texts

16 texts provided detailed material for content analysis. Most are contemporary introductions to engineering practice or prescriptions for engineering education.

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Acknowledgements

Students and colleagues in the UWA Engineering Learning and Practice Research Group contributed with many helpful discussions, and Prof. Jenni Case contributed some valuable suggestions.

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