Real Engineering is not what you learned at school...

…or is it?

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Engineering education appears to be based on certain implicit assumptions about the nature of engineering practice. The first is that engineering is a predominantly technical discipline based on scientific rationality in which design is the pre-eminent aspect alongside technical problem solving (Sheppard, Colby, Macatangay, & Sullivan, 2006). The second is that soft skills such as communication and teamwork, while important, are not really suited for learning at university, and are better learned through experience.

This paper presents research results that seem to contradict these assumptions.

Engineering education is being discussed once again in Australia as a result of widespread dissatisfaction with the "practical" skills of graduates and an engineering skills shortage, particularly in the mining and resources industries. This dissatisfaction mirrors reports from other countries on the apparent gap between engineering education and professional practice (e.g. Dillon, 1998; e.g. Florman, 1997; Pascail, 2006). These concerns continue even after fundamental changes to accreditation criteria have been introduced worldwide. In a survey to assess the effects of these changes, only about 50% of American employers thought that engineering graduates understood the context and constraints that govern engineering, and there was a majority assessment that graduate understanding had declined in the last decade (Lattuca, Terenzini, & Volkwein, 2006, Fig 9 page 12). This agrees with persistent feedback from employers in Australia that graduates lack appreciation of fundamental knowledge and engineering courses are misaligned with industry needs. Graduates themselves have acknowledged these weaknesses (Martin, Maytham, Case, & Fraser, 2005). A survey of industry requirements for engineering education in Britain found evidence of skill deficits and concern that "the grade of degree awarded can be a poor indicator of a graduate's actual abilities" (Spinks, Silburn, & Birchall, 2006). Employers expressed "a need for enhancing courses in terms of their development of practical skills but not at the cost of losing a strong theoretical base".

There are other signs pointing to the need to question the assumptions on which engineering education is based.

Few of the graduates from leading engineering education institutions in India enter engineering careers: most are employed by IT firms producing software (and associated services). The apparent driver is salary levels: IT firms pay 50,000 Indian rupees/month. (~US$16,000/yr). In engineering companies graduates earn about one third as much. Labour market theory tells us that salary levels are usually related to the marginal product created by a worker. This suggests that Indian engineering graduates do not have appropriate skills to generate as much value for their engineering employers as they can in software-related work.

Yet, if their education were well structured, they should be able to create more value in areas of work directly related to their education than in other occupations. Leading Indian engineering institutes follow typical models in leading universities in America, Europe and Australia in both content and teaching style. While there is slightly less project-based learning in India, the differences are minor. A close examination of young engineers working in a leading export-oriented Indian manufacturing company (Domal & Trevelyan, 2008) shows a large mismatch between their education and the work they are expected to do. Therefore it is not surprising that Indian graduates create relatively low value for the Indian companies employing them.

Given the pressing need to improve energy efficiency and reduce atmospheric emissions from developing countries such as India, such skill mismatches point to significant future difficulties in achieving the desired changes. Engineering performance in India and China will be a critical factor in reducing emissions and the consequences for the global environment. Anecdotal evidence points to Chinese engineering skill mismatches similar to those observed in India. Similar issues have been reported in other countries (e.g.Enshassi & Hassouna, 2005). But what is it, exactly, that we are training engineering graduates to do? What is it that engineers really do in their work, particularly novice engineers?

I have been searching for answers for the last four years with a team of colleagues and students. The first surprise was to find that there are only half a dozen or so published reports of systematic research that can help answer this question (James P. Trevelyan & Tilli, 2007). The second surprise was to learn that engineers cannot necessarily tell you everything they do: it has taken careful and patient observation to fill in the gaps.

At the heart of this issue lies an apparent contradiction. Most engineers seem to have a very narrow view of what constitutes "real engineering" and most of what they really do is something else entirely. Engineers like to think of engineering as problem-solving, calculation and design, “hard technical stuff” that they learned in engineering school.

Yet this is not what they seem to be doing most of the time. Our research provides strong evidence that engineers spend most of their time interacting with other people, engineers, technicians, clients, contractors and suppliers. They do this face-to-face, on the phone, through e-mail, reports and written correspondence.

Careful analysis of interviews with nearly 100 engineers in several countries across all disciplines suggests that coordinating technical work by other people dominates engineering practice (J. P. Trevelyan, 2007). Yet, this is not just a matter of communication skills: deep understanding of the technical issues and the ability to predict the consequences of compromises are essential to do this effectively.

The amount of time spent interacting with people might be explained in terms of engineers taking on management roles as they progress in their careers. However, a systematic study of our own engineering graduates just a few months out reveals that they also spend most of their time interacting with other people in different ways (Tilli & Trevelyan, 2008). Reports from countries such as Japan provide similar evidence (Kilduff, Funk, & Mehra, 1997). Purely technical solitary work like design is a small proportion of their daily effort.

A careful analysis of our interviews and observations has revealed 85 aspects of engineering practice ranging from design, test and inspection through to coordination, team leadership, performance assessment, cash flow management and even organising social events. Few of these receive any significant treatment in engineering schools: most are not mentioned at all (James P. Trevelyan, 2008).

A similar analysis of different types of technical know-how and concepts required to practice engineering reveals the same picture. Concept types range from knowledge of components and materials used in a particular industry through to complex issues such as knowing how to arrange work procedures to minimise the chances of mistakes being made. Of about 45 different areas, only two or three receive detailed attention in engineering courses. Nearly everything that an engineer needs in practice has to be learned after graduating, mostly on the job from colleagues.

Here is a telling comment provided by one of our own graduates responding to a survey. We asked how much time is spent each week on various aspects of reviewing, checking, testing and inspection work:

> "These questions above all feel like 'real world' questions, why do they make sense now, but I have never been exposed to this kind of stuff at uni??"

Much of the complexity in engineering practice has remained hidden behind a veil created by the language that we engineers like to use, a language in which we turn common English words into something quite different from what most people think they mean. Most people think that a model is an attractive young person who displays clothes on a catwalk, and ‘front-end loading’ is something that machine looking like a tractor does on a building site. While academics and most engineering students understand the engineering concept of a model, other terms like configuration management generate puzzled frowns.

The narrow view of what constitutes "real engineering" might be one of the main factors behind some serious issues in engineering practice. For example, many engineers regard checking for mistakes and documentation as low priority work, something that they have to do but at the same time it is seen as an interruption to "real productive work" (see also Perlow, 1999). Interactions with other people are also seen as interruptions, necessary ones, but still interruptions. Many engineers chronically underestimate the time it takes to complete their work, partly because they don't allow enough time for the necessary activities around interactions with other people, documentation, checking and eliminating human mistakes.

Another significant issue is that component failures resulting from human error are seldom recorded, let alone predicted accurately. Yet in many industries the majority of component failures are caused by people choosing the wrong component in the first place, people installing it incorrectly, people operating it incorrectly or people maintaining it incorrectly.

Examination of the content of typical engineering courses reveals around 90% or more focused entirely on analysis of objects, scientific principles and mathematics. The other 10% covers design and a little economics. Serious consideration of the human being that lies at the heart of engineering is conspicuously absent. If it receives any treatment at all, it lies on the optional periphery of the curriculum and does not receive equivalent intellectual rigour to science and mathematics-based courses. It is likely to be regarded as "a soft option", something that students should be discouraged from taking in contrast to the "hard technical stuff".

This is an interesting contrast from the view of engineers that we have interviewed who see the technical part as easy whereas getting people aligned and cooperating with each other is the really hard part of engineering.

Changes to accreditation criteria in 2000 required engineering schools to pay more attention to communication and team working skills. Evidence from the USA suggests that while students think that they have slightly better skills, employers are not so sure.

Engineering schools typically interpret the need for communication skills in terms of the ability to present technical papers at a research conference (e.g. ASCE Committee on Academic Prerequisites for Professional Practice, 2008). Team skills are said to be developed by dividing students into groups (called teams) so there will be fewer reports to mark than if each student submits an individual report. However student groups rarely behave like teams. (Gibbs, 1995) and it is rare for engineering students to learn formal team working skills in their courses.

Our research is revealing the need to bring people and serious consideration of human behaviour back to the centre of engineering, not just in practice but also in engineering schools. After all, engineering is done by people who have all the usual human frailties. Engineers nearly always have to rely on other people to deliver the value that results from their work, yet they take responsibility for the consequences. We need to provide graduates with formal concepts and ideas to help them understand human behaviour, including their self-awareness. They need to learn about effective ways to compensate for inevitable variations of human perception and behaviours so that they can practice engineering and deliver results with predictable performance, timescale, cost, safety and environmental impact.

At the moment, the practical human side of engineering is learned on the job with minimal formal introduction. Yet, would any of us recognise an engineering qualification on the assumption that graduates would learn the scientific and technical essentials on-the-job?

Such a transformation of engineering education will not be easy. However, a more balanced view of engineering as a creative social and technical discipline could have much broader appeal for today's youth. A view that combines the challenges of engaging the willing cooperation of other people with providing technical solutions to support human civilisation. Such a view might encourage many more young people to take up an engineering career with a much clearer idea of what lies ahead.

This paper will review extensive research by the author and his colleagues that has lead to these conclusions. Social theories of identity {e.g. \Ashforth, 1989 #633} may provide a coherent framework in which to review this research and predict some outcomes. The presentation will include suggestions on ways to develop solutions that could avoid common zero-sum arguments on curriculum content.

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