Submission to Senate Education, Employment and Workplace Relations Committees

Winthrop Professor James Trevelyan

Faculty of Engineering, Computing and Mathematics, The University of Western Australia

The shortage of engineering and related employment skills

Terms of Reference and Summary of Submission

(a) the implications of the shortage for infrastructure delivery in terms of economic development, cost, efficiency, safety and disputation;

> Skill shortages are costing the Australian community many billions of dollars annually because of failed engineering projects and projects that require expensive alterations to achieve satisfactory performance. Australian firms, their engineers, and other people with related employment skills are unable to match the performance of firms in similarly industrialised economies. Australian engineering firms are missing out on contracts in the mining and petroleum industries because of their failure to deliver satisfactory results in the past. Some project failures, but not all, lead to disputation.

(b) the impact of the long-term outsourcing of engineering activities by government on skills development and retention in both the private and public sectors;

> Government outsourcing of engineering has removed one of the most important means for developing effective engineering skills in Australia: the training of engineers and people with related skills within government utilities, defence and other engineering organisations. Until the mid 1980s, even to an extent today, these organisations also served as a reservoir of skilled people for the private sector to hire when needed. Recent experience demonstrates significant losses to government because of skill shortages within the government organisations and private firms that provide outsourcing capacity.

(c) options to address the skill shortage for engineers and related trades, and the effectiveness and efficiency of relevant policies, both past and present;

> Australia produces a surplus of engineering graduates but they do not have the skills needed to be effective engineers. There is little understanding of engineering practice in our universities: all the emphasis is on engineering science. Changing engineering curricula in Australian universities is not a feasible option to address skills shortages in the short or medium term.
>
> The only effective way to rebuild skills is a workplace-centred training program based on systematic research on engineering practice. Engineering practice research will, with sufficient long-term support, develop understanding of practice within universities and

engineering schools. Leading research at the University of Western Australia has demonstrated that very little is understood about engineering practice, worldwide. There is an urgent need for research to understand what people actually do in order to achieve effective engineering. Without this research, it will not be possible to develop effective education strategies to rebuild engineering skills in Australia.

In addition, there are numerous information gaps in the job market that inhibit employment of engineering graduates in Australia.

(d) options for infrastructure delivery using alternative procurement models which aim to foster collaboration and achieve effective community outcomes, including skills development and retention;

As the major infrastructure owner in Australia, government can use infrastructure procurement as a means to foster skills development and retention. This submission suggests several ways to do this.

(e) effective strategies to develop and retain engineering talent in the private and public sectors through industry training and development, at enterprise, project and whole-of sector levels;

Using recent Australian research on engineering practice as a base to provide effective education and training intervention, there is an opportunity in Australia to rebuild our engineering skills base and take advantage of our unique research lead in this area.

There are opportunities for government intervention to reduce or eliminate information gaps that inhibit employment of engineering graduates in Australia.

(f) opportunities to provide incentives to the private sector through the procurement process to undertake skills development;

One way to provide a suitable incentive to the private sector would be to provide funding for engineering and related skill development within firms as part of government procurement in the engineering sector.

(g) consequences of skills shortage in the construction sector to the public sector's capacity to effectively procure and manage infrastructure projects;

While evidence suggests that infrastructure construction is not as badly affected by skill shortages as the mining and petroleum industries, recent reports clearly demonstrate the consequences of engineering skills shortage issues in infrastructure and public utility services. As a community, we carry the costs of these deficiencies. We have the opportunity to fix this problem.

(h) the impact of delayed and stalled infrastructure projects on economic development, workplace productivity and employment; and

Delays and capacity issues with infrastructure affect our ability to take advantage of the commodities boom. We are missing out on opportunities because of skill shortages.

This enquiry focuses on engineering and related employment skills.

Research for this submission

This submission is based on research on engineering practice at the University of Western Australia since 2001 by a team of academics, postgraduate students and undergraduate students in the Faculty of Engineering, Computing and Mathematics – the Engineering Learning and Practice Research group. This research has been mostly privately funded with many contributions from major industrial companies, as well as small and medium sized firms. The main government contribution has been support for postgraduate student scholarships under the research training scheme. Our research covers all engineering disciplines, including software engineering, and has been based on studies of engineering enterprises and individual engineers in Australia, India, Pakistan, Brunei, and elsewhere.

What do engineers do?

Engineers conceive, design and arrange the delivery of infrastructure, products and services with predictable capital and operating cost, timescale, performance, quality, reliability, maintenance and support requirements. They do this with the most economic possible use of material resources and human effort in a way that contributes to long-term sustainability of human society, and with acceptable environmental and social impact.

Engineers collaborate with a large number of other people with related skills to deliver infrastructure, products and services. These include, but are not limited to, technicians, technologists, artisans, tradespeople, contractors, financiers, component and material manufacturers, importers and suppliers, regulators, accounts, lawyers, enterprise owners, and people in local communities.

Effective engineering reduces human effort and material resource consumption needed to meet human needs so that people can enjoy a high standard of living with education, social support services and good governance.

High quality engineering capacity encourages investment, leading to greater employment and wealth accumulation for the community at large.

Australia, as we know it today, could not be sustained for long without the contributions of engineers and other people with related skills, particularly for water supply, sanitation, energy, transport, communications, shelter, food transport, processing and distribution and even healthcare.[1]

What are the characteristics of the engineering skills shortage?

1. Recruitment difficulties and employment market information gaps

The primary indication of the skills shortage are reports by numerous companies that they are having difficulties in finding suitably qualified engineers (and people with related skills) for the work that they are undertaking.

[1] Trevelyan, J. P. (2010). Reconstructing Engineering from Practice. Engineering Studies, 2(3), 175-195.

In a recent research interview with a major company that supplies engineering services to the mining industry, they indicated that currently they have between 400 and 700 vacant positions in a workforce of about 4000. They are now sending recruitment specialists to European countries experiencing economic downturns in an attempt to find more suitable applicants. The number of vacancies has been higher at times, but has not been lower in the last few years.

Our research has revealed many information gaps and blatant discrimination that inhibit employment of skilled migrants already in Australia.

Most graduates do not acquire appropriate job seeking skills.

Recruitment agencies do not provide accurate or appropriate information to help employers make suitable choices.

State government agencies provide limited support services and there is a paucity of information that is helpful, particularly for migrants.

There is widespread ignorance and there are discriminatory practices among employers, employment agencies, and migration agents and lawyers. Many, *including agencies of government*, are exploiting migrants.

Many temporary migrants on business-sponsored visas feel very insecure without permanent residence rights and are too frightened to approach police or other government enforcement agencies. They believe these agencies might provide information to the immigration department that would compromise their chance of gaining a permanent resident visa, or even a temporary visa extension.

The settlement needs of skilled migrants are poorly understood within state government agencies, employers, and recruitment agencies and this reduces employment opportunities because the needs of spouses and children are not well supported.

Migrants have low confidence in government agencies because there is widespread failure to protect employment rights of migrants. Firms can exploit migrants with relative impunity.[2]

2. Australian project performance lags behind our industrialised competitors

A second dimension of the skills shortage is our relatively poor performance in delivering satisfactory results from many engineering projects. According to recent estimates by an independent assessment of around 60 billion dollars spent on capital expansion projects annually, Australia's performance is significantly worse than other industrialized countries with equivalent economies.[3] In the case of major capital expansion projects that the mining, gas and petroleum industries depend on, between 10% and 20% of projects are written off by their owners, costing billions of dollars annually. A recent public example is the Ravensthorpe nickel project by BHP, sold for less than 10% of the cost. Around half of all projects in this category fail to work, requiring expensive modifications to be made. 70% fail to reach their design capacity. We complete projects later, at greater cost, and with more deaths and injuries than in other comparable countries. Infrastructure

[2] Further details are available on request: the author is currently engaged in a research project for the WA State Government on improving information resources for skilled migrants in WA.

[3] Further details available on request.

projects are among the better performers: the worst performances seem to be in the mineral and resource processing area.

Recent reports into navy engineering in Australia demonstrate that these issues don't just affect private companies: government outsourcing of engineering is affected in the same ways.

Unfortunately, most of these project failures occur in the private sector and are well hidden: those responsible don't want their failures to become known, especially to shareholders. As an example, in one of my recent research interviews, an engineer stated that "we probably went down around 1.5 billion on that one (referring to a recent project failure), but because commodity prices rose so spectacularly that year, the shareholders never noticed and we capitalized the loss."

Understandably, these issues are confronting for the Australian engineering community. They blame the issue on "management failures". There is little doubt that these difficulties lie with project delivery, the practical aspects of converting engineers' ideas into reality so they can provide real value for investors. Often projects are rushed through approval processes in companies to take advantage of temporary commodity price rises, and projects go out to engineering firms with much of the detailed engineering design still to be completed. Engineering firms hired to construct expensive plant and equipment often don't get to see the final project results: their concern is just to deliver part of the overall project on time and budget. Therefore, many engineers in Australia find it hard to accept that there really is a problem on the scale reported.

Whether we like it or not, these failures are affecting government and firms with household names, firms in which we invest our savings and pension funds. As a community, we share the ultimate cost of these failed investments, even though we never get to know the details. Usually, we only get to hear about large government project failures. As a result, many think the problem lies with government, not private firms. However, private firms are able to keep their secrets hidden for longer. My research has provided evidence that even senior executives relatively close to these failures miss out on a deep understanding of what happened, partly because they don't want to know.

Skill Flows in Australia

It is helpful to understand where our engineers and other people with relevant occupational skills are coming from.

Figure 1 illustrates the supply of engineering skills from different sources: tertiary educated students, skilled migrants entering with permanent residence, and business-sponsor migrants on 457 visas. The size of the flows is represented approximately by the diagram, though it should be noted that the annual number of new 457 visas issued has fluctuated significantly in recent years.[4]

Most Australian resident students graduating from engineering courses tend to gain their first job with larger firms who have the resources to provide between three and four years of on-the-job training and professional development. Smaller firms prefer to recruit experienced engineers because they are less able to provide the depth of support needed for early career professional development. Only a minority of Australian-born engineering graduates remain in engineering-

[4] Immigration Update 2010-2011, Department of Immigration, Canberra

related employment. There is significant attrition as many graduates discover that engineering work is not what they imagined it to be, and some leave for family responsibilities, particularly women. Women also still find significant direct and indirect discrimination: the proportion in the engineering workforce as a whole is significantly less than the proportion who have graduated in the last few decades.[5]

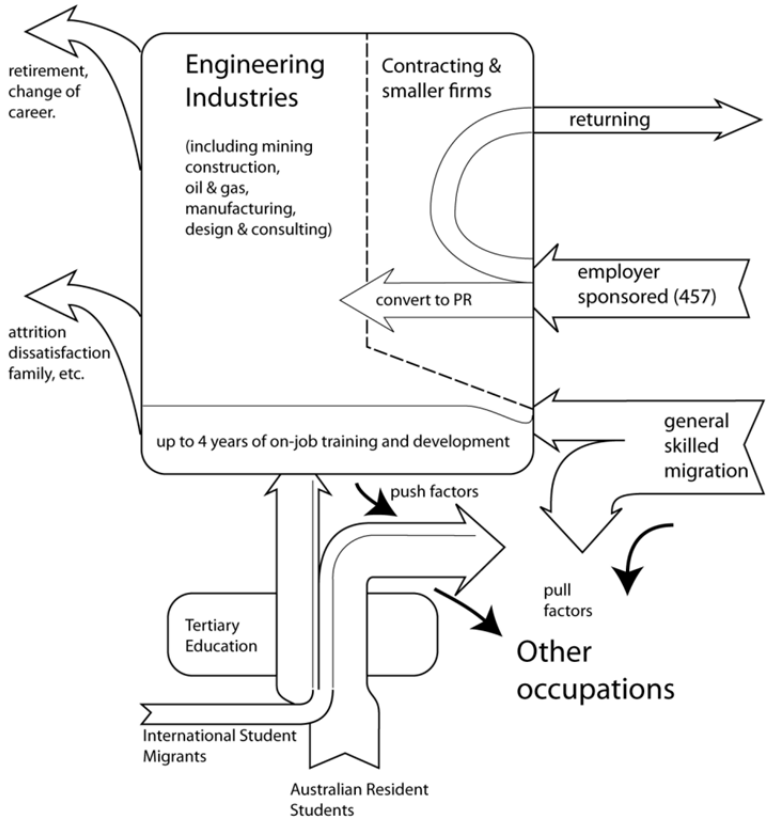

Figure 1: Engineering skill flows

Migrants who entered Australia for tertiary studies in engineering are significantly less likely to enter engineering-related employment than Australian-born students. This particularly affects students from South and South-East Asia.[6]

There are some significant "push" factors that deter graduating students from entering an engineering-related career. Many firms have rigid and restrictive recruitment "windows" to suit internal training schedules: they only recruit at a certain time during the year. Others have cumbersome and time intensive screening processes such as extensive online psychometric testing: this also deters potential employees. Many bright students think that the majority of firms do not offer sufficient intellectual challenges and choose alternative careers.

[5] Mills, J., Mehrtens, V., Smith, E., & Adams, V. (2008). An Update on Women's Progress in the Australian Engineering Workforce (pp. 45). Canberra: Engineers Australia.
[6] Trevelyan, J. P., & Tilli, S. (2010). Labour Force Outcomes for Engineering Graduates in Australia. Australasian Journal of Engineering Education, 16(2), 101-122.

There are also significant "pull" factors that attract students graduating in engineering into other occupations. The finance industry, at times, has recruited many of the best graduates from engineering schools. Other students are attracted by the possibility of humanitarian work and think that there are other ways of making a more positive contribution to the world.

As in the case of graduating students, only a minority of skilled migrants remain in engineering-related employment out of those who enter Australia with engineering qualifications, permanent residence rights and work experience. There are significant pull factors: many discover that they can earn more in capital-city occupations such as taxi-driving. The relative social status of engineering in Australia, as a profession, is considerably less in Australia than it is in some other regional countries, particularly South Asia. Also, difficulties in the employment market experienced by fellow migrants deter others from seeking work in engineering. Nevertheless, for several regions of origin, the proportion of these migrants who remain in engineering-related employment is still greater than the proportion of international students graduating in Australia who remain in engineering-related employment.

Most firms recognise that migrants entering with engineering work experience require much less initial training and professional development than recruiting graduates from Australian tertiary engineering courses. There is still some training required, however. Not all firms appreciate the value of a diverse engineering workforce. However this is changing as engineering firms start to explore opportunities for outsourcing engineering work to countries such as India, the Philippines, and Indonesia. Valuable personal connections, knowledge of local languages and of engineering business culture are now being valued by many local firms.

The larger established firms in engineering industries prefer to employ permanent residents because of the large investment in training and learning about the firm's internal processes. They also have experience of boom and bust cycles in engineering work and prefer to work with a significant proportion of their staff on contracts: the staff can easily be laid off if the volume of work decreases. For this reason, employer-sponsored temporary migrants on temporary visas tend to work with contracting firms and agencies, and only transition into the larger firms if and when they gain permanent residence.

The large growth in employer-sponsored temporary migration (457 visa) reflects the difficulties that firms have encountered in recruiting appropriately skilled engineers and other people with related skills. Smaller firms have difficulty in finding sufficient resources to develop their own engineering graduates to a comparable level of skill. Even larger firms prefer to recruit temporary migrants who have a good chance of converting to permanent resident status, some employing them indirectly through agencies while they remain on temporary residence visas.

The current high levels of under-employment and unemployment in engineering sectors in European countries, the USA, Canada, even in some East Asian countries, has greatly increased the international supply of people with engineering skills. The availability of these people has led some firms, particularly those representing large international engineering firms, to significantly reduce their local recruitment and professional development commitments. These firms also, to an extent, are governed by recruitment policies emerging from head office is located in regions of high engineering unemployment and low recruitment.

Is there a shortage of engineering graduates in Australia?

Many have argued in the past that engineering skills shortages could be solved in the long term by attracting more students, particularly international students, to study engineering related courses in tertiary institutions. Some have gone further, arguing that this is the only way to solve the problem.

Analysis of ABS census data[7] demonstrates that a minority of engineering graduates in Australia work in engineering-related occupations, including paraprofessional and engineering-related management. Around half work in other occupational areas. In Canada, with a similar industrial base to Australia, the proportion working in engineering-related occupations is significantly higher.

For various reasons, a large proportion of engineering graduates in Australia either do not enter engineering-related occupations at all, or leave engineering-related occupations relatively early in their careers.

The statistical data has demonstrated that migrant engineers educated outside Australia tend to be less successful in finding engineering-related employment than locally born and educated Australians. It also shows that migrants who came to Australia only for their tertiary education, who arrive between the ages 18 and 25, are even less successful, particularly if they came from South Asia.

Our research has uncovered several pertinent factors. Migrants who come to Australia for tertiary education frequently choose their courses on the advice of parents. Engineering, medicine and law are very highly regarded professions in South Asia in particular, also to a lesser extent in other parts of Asia. However, on reaching Australia, many international students realise that there are other possibilities for rewarding careers in Australia. While they may complete their degrees, they may never practice in the profession for which they were trained, particularly engineering. The social standing of engineers in Australia is considerably less (relatively speaking) than in South Asia. Further, some occupations can provide much greater remuneration in the first few years than engineering. We have evidence, for example, that young people who are prepared to work hard can earn more (after tax) driving taxis than they can as engineers, even with several years of experience. Taxi drivers also enjoy flexibility in working hours that few engineers can hope for.

The combined annual intake into university engineering courses in Western Australia is approximately 2200 students. (UWA 950, Curtin 800, Murdoch 150, ECU 300). This represents about 11% of the cohort of students who graduated from secondary education in Western Australia in 2010. Given that engineering students are approximately 86% male, this represents about 20% of the completing male cohort. It is difficult to imagine that we can attract a larger number of students into engineering courses, unless a strong effort is made to improve female participation. Unfortunately, female participation has been declining over the last decade. Even though many

[7] Trevelyan, J. P., & Tilli, S. (2010, December 6-8). International Students' Employment Outcomes: Cause for Concern. Paper presented at the Australasian Association for Engineering Education Annual Conference, University of Technology, Sydney.
Trevelyan, J. P., & Tilli, S. (2010). Labour Force Outcomes for Engineering Graduates in Australia. Australasian Journal of Engineering Education, 16(2), 101-122.

attempts have been made to understand the reasons for this, it has not been possible to reverse this trend.

Regardless of the causes, it is difficult to argue that there is a shortage of engineering graduates in Australia. Further, it could be difficult to recruit more students into engineering courses unless more female students can be attracted into engineering. This has proved to be very difficult in the past.

Options for Intervention

Improving Job Market Information

Part of the skills shortage can be explained by inadequate information available within the employment market. There are many opportunities for government to intervene in the employment market to improve the quality of information available for both jobseekers and employers.

Our research has exposed significant information deficiencies that could be remedied.

Engineering graduates emerge with few if any job seeking skills. Interviews have revealed that career advice provided by tertiary institutions is of poor quality and inappropriate, particularly for international students seeking employment in Australia. Australian-born engineering graduates have become accustomed to being highly sought-after. The effective education transfer of job seeking skills requires the same level of education investment as the more conventional aspects of the engineering curriculum. At the moment, the education resources devoted to this aspect of education are insufficient for effective learning.

Employers report that they reject up to 95% of internet job applications because of the way that they have been written. They admit, in interviews, that many of the rejected applications probably come from qualified engineers who could do the job just fine. However, a typical Internet advertisement prompts 500 or more applications in a couple of days and employers need a quick way to reduce the number they need to consider more closely.

Firms have told us that recruitment agencies provide a poor service both to employers and applicants. Agencies provide them CVs of applicants who they have already employed some time earlier, and others who are obviously unsuited. Firms organising employment fairs (and most employers) have outdated or incorrect information on visa employment rules and, for example, often refuse to consider any job applicant who does not yet have permanent residence.

Employers place a high emphasis on the ability to communicate in English, both formally in writing and informally in social situations. The latter is particularly important in maintaining a safe workplace: safety relies a great deal on informal communication, much of which can be in work-related social settings. Employers typically screen applicants with a short telephone interview. Migrant engineers, from non-English-speaking background, or even from a South Asian English speaking background, particularly international students, often do not appreciate the importance of informal English communication skills. They will often share accommodation with others of the same background and not practice social communication in English with speakers from a different background. This disadvantages them in the job market.

There are many practical initiatives that government could support to improve job market information among relevant actors.

1) Providing resources to assist engineering graduates, particularly migrants, to prepare written job applications and CVs that provide concise and accurate information on their previous work experience and capabilities. The agencies that provide the service can also provide feedback on telephone interview skills and advice on improving conversational English.[8]

In the words of one employer: *"I want someone who can reflect on what they've done, like this: 'in doing that, I learned this and this and this, and when I'm an engineer, I will make sure that I never design something like that.' That's more the kind of person I'm looking for, somebody with ability to learn and reflect on what they have done, with an understanding about the context in which the work is being performed at why it is relevant."*

2) Provide incentives for universities and colleges to include an understanding of the engineering employment market and job seeking skills as an assessed component of tertiary education. This would need to include an understanding of and an ability to operate in the informal job market, and professional or occupational networking skills.

3) Provide resources, possibly through state government agencies, to provide public information for jobseekers, and particularly migrants, on engineering companies recruiting skilled personnel. Information would include the types of engineering activity they are involved with, the types of skills that they require, and information on how to approach the firms informally as well as responding to formal advertisements.

4) Work with state governments to help maintain the employment rights of migrant workers, particularly those on temporary and student visas. Enforcement must include not only wages and salary, but also actual working hours and conditions relative to other workers. This measure is necessary to protect the reputation, trust and respect for all government agencies, including the immigration department, since most migrants believe that the action (or absence of action) by one agency reflects the attitude of all.

5) Provide better information resources, possibly through state government agencies, to address secondary settlement needs of migrants, particularly the provision of accurate information on public transport, medical and hospital care, obtaining low-cost accommodation through informal agencies such as Gumtree, assistance with placing spouse and family members in appropriate accommodation, employment and education. This information needs to be provided by government agencies, employers, recruitment agencies, and informal networks.

6) Provide resources for professional and occupational associations to assist recent graduates and migrants with engineering qualifications to meet and enter their chosen community of practice. These organisations, with appropriate support, could provide effective mentoring, networking, and temporary membership until they obtain relevant employment. The development of ethnically distinct networks (rather than the existing technical discipline and expertise-based networks) would be more valuable in helping new skilled migrants enter appropriate employment more quickly. Chinese engineers, for example, are severely impacted by the lack of a local network as this is a

[8] More details available on request from the author

dominant feature of life in their home country.[9] Continuation of this support should be contingent on migrants attending relevant technical meetings and participating in other organisational activities.

7) Provide support to extend the scope of the Engineering Professional Year program beyond basic non-technical skills relevant for engineering employment. While this is a good program in principle, its coverage is extremely limited (it only deals with generic skills) and does not address many of the fundamental misconceptions about engineering among graduates and novice professionals.

8) Provide resources for state governments to work with companies and recruitment agencies to improve knowledge about visa classes and employment rules. This could include, for example, certification or accreditation for agencies who can demonstrate that they can provide accurate advice relating to engineering employment issues, visa rules, and assistance available from different agencies, etc. Training, certification and monitoring of migration agents and lawyers are particularly important components that need to be addressed.

Missing Skills

Since there are plenty of engineering graduates currently, part of the problems experienced by companies trying to recruit skilled engineers can also be explained by the absence of appropriate skills in engineering graduates from Australian universities. The performance of firms failing to complete projects satisfactorily, even though there are commercial agencies that provide advice and training, demonstrates that intervention within firms is also needed.

What are these missing skills?

Research on engineering practice at The University of Western Australia has provided a much clearer understanding about professional engineering skills than has been available before.

We have identified numerous ways in which existing university courses enable students to develop persistent misconceptions about engineering practice that interfere with their subsequent ability to learn effectively in the workplace.

For example, there is a common perception among students and in the wider community that engineering work consists largely of solitary technical work using computers and related tools. Popular culture frequently portrays engineers as socially inept people who work with computers and, in the past, with drawing boards. Engineering students share the same perception and see themselves working predominantly on design and technical problem-solving in their future careers.

Research demonstrates that professional engineering practice is quite different to what most students and other people imagine. Engineers, on average, spend about 60% of their time communicating directly with other people, predominantly other engineers. Only a relatively small proportion of their time is spent on solitary technical work.[10]

---

[9] Bo, N. J. (2011). A Clash of Engineering Cultures. B. Eng Thesis, The University of Western Australia, Perth.
[10] Trevelyan, J. P., & Tilli, S. (2008, June 20-22). Longitudinal Study of Australian Engineering Graduates: Preliminary Results. Paper presented at the American Society for Engineering Education Annual Conference, Pittsburgh.

Unfortunately, the communication work that engineers spend much of their time on bears little resemblance to the communication skills on which their performance is assessed in tertiary education courses. Students think that effective communication is: i) the ability to write technical reports and ii) occasional verbal presentations supported by images and text on a screen.

Communication skills required in the workplace are quite different. Engineers spend up to 30% of their time, on average, coordinating technical work performed by other people, mostly without any formal organisational authority. Much of this comprises requests to provide information or skilled performances in different ways.

Few if any engineers have sufficient technical understanding by themselves. Instead, engineering practice relies on knowledge distributed in the minds of all the participants: engineers, technologists, artisans and many others. Engineering practice, therefore, relies on gaining the willing and conscientious cooperation of many people in a coordinated series of performances, each person contributing his or her own particular knowledge and skills, backed up by varying degrees of experience. Much of the 'art' of engineering practice involves both informal and formal techniques that help produce predictable results from countless individually unpredictable human performances.

Engineering practice can be understood as two different intellectual activities, portrayed in the following diagram.

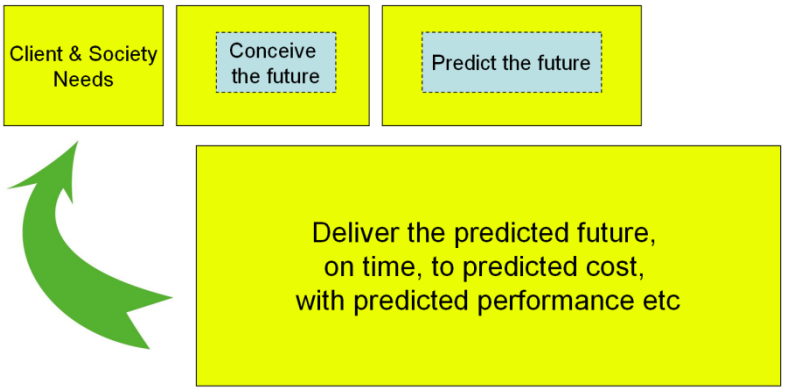

Figure 2: A simplified model of engineering practice

The upper thread comprises three phases. It starts with discerning, comprehending and negotiating client and society needs, and discussing engineering possibilities with clients and the wider society. The second step is conceiving engineering solutions that would meet those needs. The last phase is performance prediction: working out the technical performance and the cost of proposed solutions. Engineering education focuses mainly on a subset (shaded) of the two latter phases.

The lower thread is rarely mentioned in engineering education: delivering solutions that meet the needs and requirements, on time, on budget, with the predicted performance, safely, and with minimal environmental and social impact. Yet this is where most of the work lies. Without this second thread, engineering would not yield anything useful. Solutions on paper, no matter how elegant, provide little value until they can be translated into reality.

The large arrow represents the idea that experience in the delivery aspects of engineering in the lower thread enables an engineer to develop expertise that helps with discerning client requirements, creating new ideas and predicting performance in the upper thread. This is like a feedback loop: engineers can get progressively more and more expert as they learn from experience.

A Youtube video recently produced by the WA Department of Training and Workforce Development provides an insight into this aspect of engineering.

http://www.youtube.com/watch?v=CvY-GZuWo-4

These research discoveries have helped to explain some of the issues that lie behind skills shortages in Australia.

Many young engineers are initially puzzled, frustrated, and disappointed after commencing their first engineering job. It is not unusual to receive reports from recent graduates that they feel "entirely incompetent" or that they think that they are not doing any "real engineering work".

There is nothing new about this.

Young engineers in the 1960s, on commencing their first job in a public service utility, would often remark that the work was dull, routine, and consisted mostly of administrative work such as writing specifications. Technical challenges were few and far between.

Many young engineers leave for other occupations after spending several years seeking the intellectual challenges for which they were trained, without success. However, those that remain settle down and realise that the real intellectual challenges in most engineering occupations involve people. Technical solutions, by themselves, have little relevance without taking into account the interests and abilities of different people.

The ability to produce practical results within engineering enterprises, the delivery thread of engineering practice portrayed in figure 2, "the ability to get things done", are the most highly valued by most engineering organisations. However, as explained above, this aspect of engineering practice receives little if any attention in engineering research and education. More than anything else, this factor explains current skill shortages in Australia.

Supporting evidence for UWA research has recently appeared in reports from the Australian National Engineering Taskforce project.[11]

Project delivery skills were developed in the experiential learning programs run by public service utilities up until the 1980s.

---

[11] Watson, L., & McIntyre, J. (2011). Building engineering workforce capacity through education and training: Australian National Engineering Taskforce (pp. 107). Canberra: University of Canberra….
Wise, S., Schutz, H., Healy, J., & Fitzpatrick, D. (2011). Engineering Skills Capacity in the Road and Rail Industries: Australian National Engineering Taskforce. Sydney: Workplace Research Centre, University of Sydney, and National Institute of Labour Studies, Flinders University.
King, R., Dowling, D. G., & Godfrey, E. (2011). Pathways from VET Awards to Engineering Degrees: a higher education perspective. Canberra: Australian National Engineering Taskforce (Australian Council of Engineering Deans).

The main difficulty that faces Australia today is that we have lost most of our capacity to develop these skills.

Research on engineering practice is very new: only a tiny number of research reports have appeared over the last 40 years, and around half of all the reports (in number rather than size) have emerged from the research group at The University of Western Australia. Over the last few years, on average, fewer than 10 research reports have appeared annually.

It will take some time for research to provide a solid base to rebuild our capacity to develop engineering practice skills.

Australia is not alone in facing this issue. However, engineering firms based in other countries often have a greater capacity to provide education and training than Australian firms.

The research that has been done in Australia has provided a valuable opportunity to rebuild our skills base.

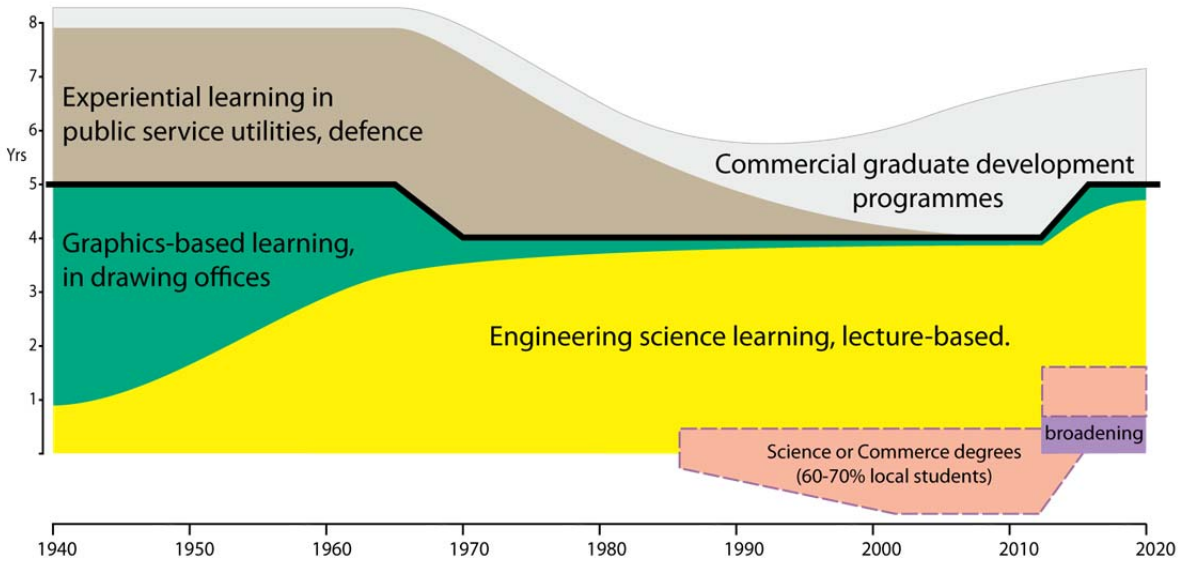

Figure 3: Engineering education trends

Figures 3 and 4 illustrate trends in engineering education over 8 recent decades. Until the 1960s, engineering was a five year, extensively practice-oriented course centred on the use of graphical techniques and taught mainly by former practitioners. Since the 1960s, engineering education has become increasingly science-based, taught by people who have limited, if any, first-hand significant experience of engineering practice. Until the mid-1980s, undergraduate engineering education (below the solid black line) was complemented by experiential learning in public service utilities and defence agencies who employed up to 70% of engineering graduates in Australia. These institutions were inefficient, partly because they were training grounds for engineers who then became available to the private sector as and when required. Since the 1980s the impact of this experiential learning has decreased in both number and extent and has only been partly replaced by training programs in

private firms.

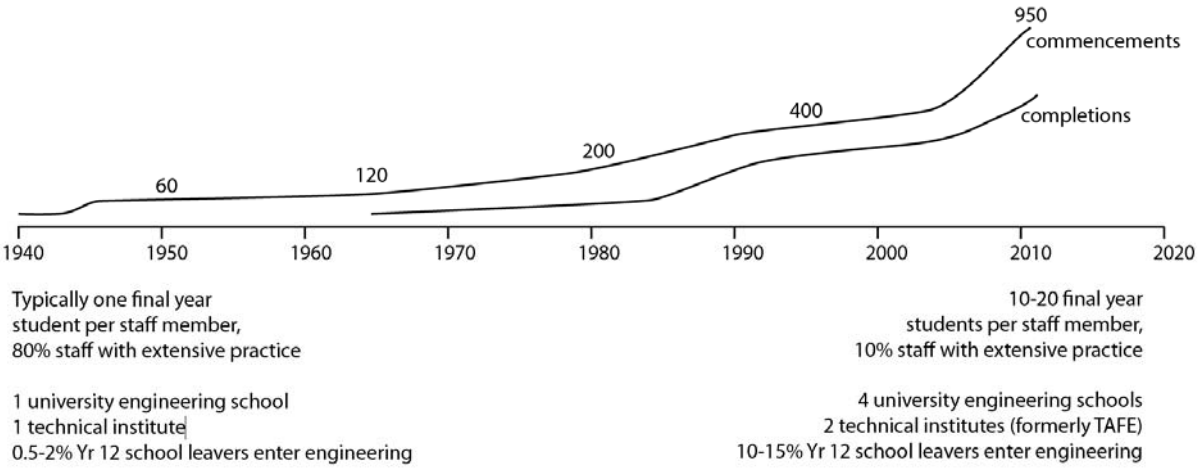

Figure 4: Approximate enrolment trends and student-staff ratios at the University of Western Australia

Figure 4 illustrates the huge change in the number of engineers being educated. Although it represents data from only one institution, this is representative of Australia as a whole. It helps to demonstrate that the ability of the engineering education system to provide any kind of serious preparation for professional practice has almost vanished.[12] It should be noted that the ability of formal education institutions to fully prepare engineers for professional practice was recognised to be very limited, even in the 1950s and 1960s.

The large government investment in post-tertiary skill development for engineers in government-owned engineering organisations up until the 1980s helped to create a climate in which companies did not need to invest in their own education and training capabilities. It is only recently that major companies have seen the need to do this. However, our research demonstrates that even large and well-established engineering firms are having difficulties in deciding how to go about training and developing their own engineering workforce. For example, at least one large (multinational) engineering firm in Australia has decided that their graduate engineers could run the graduate development program better than their own staff. In another large firm, the graduate development programme is run by an inexperienced secondary school Japanese teacher with no engineering knowledge at all.[13]

What can be done to rebuild our capacity to develop effective engineering skills?

There are two separate issues identified above.

1) Most engineering graduates do not have skills and capabilities that firms need, and the firms do not have the capacity to help graduates develop these skills.
2) Engineers already employed, and the firms that employ them, have not been able to develop skills needed to deliver project results effectively, at a level comparable with other similarly industrialized countries.

[12] Cameron, I., Reidsema, C., & Hadgraft, R. G. (2011, December 5-7). Australian engineering academe: a snapshot of demographics and attitudes. Paper presented at the Australasian Conference on Engineering Education, Fremantle.

[13] Personal communications, notes with author.

These missing skills are not well understood in the engineering community: it is only recently that research on engineering practice has provided some detailed written understanding on some of them, and no training material has been produced so far.

Much of the understanding that does exist is tacit, and cannot easily be passed on to engineering novices. Misunderstandings that develop in formal university education actually prevent young engineers from learning effectively in the workplace.[14]

Could changes in engineering school curricula help?
Yes, but only in the long term.

First, engineers already working have completed their formal education. Postgraduate coursework qualification is not a popular option in the Australian engineering community currently: most prefer to learn on the job. So far, research on engineering practice has not yet provided teaching material to serve as a base for coursework.

Second, university engineering curricula around the world have standardized on a common model and while changes might be desirable, they would take time to agree on, and implement.

Third, there is almost no understanding of engineering project delivery issues and skills in engineering schools. With the current emphasis on research performance, recruiting suitable experienced people to teach students undermines many current university performance objectives.

Fourth, and by far the greatest obstacle, the reality of engineering practice conflicts to such an extent with ideas held by the current generation of engineering faculty staff that even gaining support for research initiatives and curriculum change is almost impossible. The research at UWA has been almost entirely privately funded: it was not possible to obtain support for this research within the Australian Research Council mechanisms.

Therefore, solutions need to be centred on workplace education backed up by detailed research on engineering practice. It is only in the workplace setting that young engineers can begin to appreciate the extent to which they need to change their preconceived notions of practice inherited from their formal education and upbringing.

Research is needed
At the moment, the annual output of research papers on engineering education, just in Australia, outnumbers the *entire world's research output* on engineering practice by around 30:1. Even though human civilization depends on engineering, there is little research that would help us understand how engineers achieve the results that they do.

We have only just begun to understand so much that we have taken for granted. It was only recently that I came to realize that the fundamental reason for doing engineering, how it produces useful economic value for society, has been omitted from all recent text books.

Research is needed to provide a rich understanding on how engineers achieve effective results in order to be able to provide learning materials for novices, and effective guidance and mentoring.

---

[14] Trevelyan, J. P. (2011). Are we accidentally misleading students about engineering practice? Paper presented at the 2011 Research in Engineering Education Symposium (REES 2011), Madrid.

Just as business schools have enriched our ability to develop effective and productive organizations by building on behavioural research, we need to do the same in engineering. Business schools cannot do this because they cannot see the technical dimension that distinguishes engineering practice from generic organizations for which all current organisational behaviour theory has been developed.

Workplace Training Solutions

Workplace learning based on this research will provide the main means by which we can overcome the issues that led to this enquiry. We need this to reskill our engineers.

The size of the losses currently being sustained from project delivery failures is difficult to estimate. A figure between 5 billion dollars and 15 billion annually seems reasonable, based on estimated failure rates referred to previously.

Therefore, it would be worth investing, eventually, between $100 million and $200 million annually in rebuilding our engineering skill base if these failures can be largely avoided as a result. Investment on this scale would be sufficient to provide an Australia-wide system for workplace training for engineers, alongside a significant research effort (around $5-10 million). Companies would contribute part of the cost.

Research has to come first because there is so little previous research that can help us create an effective workplace learning curriculum and pedagogy. There has been valuable research on workplace learning (done partly in Australia) but not yet enough to build a strong base for effective pedagogy.

To be effective, training solutions must deal with persistent misconceptions about engineering practice that are reinforced by education and perpetuated by workplace mythology.

No current institution has the capacity to organize and deliver workplace this type of training on this scale for engineers.

Some of the existing organizations who could work together to develop this capacity include:

- Engineers Australia, together with its training arm, Engineering Education Australia
- Association of Professional Engineers, Scientists and Managers, Australia
- Business Council of Australia
- Australian Minerals Council, and other industry associations
- The University of Western Australia (currently hosting about half the world's tiny effort on engineering practice research)
- National Centre for Vocational Education Research

I have prepared a proposal for a National Academy of Engineering Practice[15] that could, with the support of these organisations, provide the capacity to deliver effective workplace training throughout Australia. However, it will take time to build an effective institution from these stakeholders.

[15] Available on request from the author

The other issue touched on earlier, though offering few worthwhile short term benefits could, nevertheless, provide some very effective long term solutions. The current gender balance in engineering practice, about 95% male in professional engineering, with even fewer women in paraprofessional roles, implies that we are probably missing out on many potentially outstanding engineers who happen to be women.[16] One potentially worthwhile research direction that has not yet been tried would be to understand why so many women take up engineering in the Middle East. Turkey and Iran are not often cited as examples that demonstrate gender equality, yet the participation of women in engineering in both countries is far higher than in Australia, around 35%.

In the long term, finding ways to bring more women into engineering could also help to solve long term engineering skill shortages.

[16] Julie Mills from the University of South Australia has researched this issue, for example, Mills, J., Mehrtens, V., Smith, E., & Adams, V. (2008). An Update on Women's Progress in the Australian Engineering Workforce (pp. 45). Canberra: Engineers Australia.

Reference Information

The shortage of engineering and related employment skills

- Information about the Inquiry
- Terms of Reference
- Getting involved in Committee inquiries
- Upload Submission Online
- Submissions Received

For further information, contact:

Committee Secretary
Senate Education, Employment and Workplace Relations Committees
PO Box 6100
Parliament House
Canberra ACT 2600
Australia

Phone: +61 2 6277 3521
Fax: +61 2 6277 5706</
Email: eewr.sen@aph.gov.au</

Information about the Inquiry

On 07 November 2011 the Senate referred the following matter to the Senate Education, Employment and Workplace Relations Committees for inquiry and report.

The Senate referred to the Committee an inquiry into the nexus between the demand for infrastructure delivery and the shortage of appropriate engineering and related employment skills in Australia.

The committee has been asked to consider the implications of the shortage for infrastructure delivery and the impact on economic development, cost, efficiency, safety and disputation, and the long term outsourcing of engineering activities by government on skills development and retention in both the private and public sectors.

The committee will consider options to address the skill shortage for engineers and related trades, for infrastructure delivery using alternative procurement models, and to consider effective strategies to develop and retain engineering talent in the private and public sectors through industry training and development, at enterprise, project and whole-of-sector levels. Incentives to the private sector through the procurement process to undertake skills development, and the consequences of skills shortage in the construction sector to the public sectors' capacity to effectively procure and manage infrastructure projects will also be explored.