Preparing the next generation of engineers: what will an engineering graduate of 2035 look like?

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Introduction

The Australian university system has a long and proud history of producing professional engineering graduates who have made significant contributions to engineering excellence in Australia and elsewhere. However, there are many changes occurring or on the horizon that give concern for the future preparation of professional engineers. These changes include: the changing nature of work including professional engineering work; rapid advances in technology; automation of both repetitive and creative intellectual tasks; global connectivity and communication and the ubiquitous availability of specialist information to everyone; increasing globalization, changing societal expectations and evolving human needs to name but a few.

In 2018 the Australian Council for Engineering Deans (ACED) commissioned a scoping study to inform leaders of engineering education programs and the engineering education community of the significant drivers of change in professional engineering roles and potential impacts of these changes on the expectations of graduates as we approach the year 2035. This paper reports crucial findings on the anticipated nature of future professional engineering work, expectations of graduates and key messages about changes in engineering education. The paper concludes with a summary of the recommendations for further work.

Methodology

The scoping study canvassed literature on future trends in professional work, engineering industry, and higher education. The study then consulted a small number of thought leaders representing a range of business and community interests, and engineering educators to canvas key stakeholders' views on what such changes mean for the future of professional engineering work and engineering education in Australia. Semi-structured 1-hour interviews were conducted by Lee, King and Hargreaves to explore the views of eight thought leaders from a range of engineering and industry interests on the anticipated professional engineering roles and expectations of professional engineering graduates in 2035. Interview questions were organized around 5 themes: Engineering roles; Engineering thinking; Engineering knowledge, skills and attributes; Engineering education priorities; and Engineering education pathways in 2035. Interviews were transcribed and analysed to extract key themes, with the work approved by the University of Queensland Human Research Ethics Committee.

Consultation was also undertaken with the Australian Council of Engineering Deans via a round table discussion to collect members' views on anticipated changes in: professional engineering work; knowledge, skills and attributes expected of graduate professional engineers; and engineering education programs' curriculum and pedagogy. The Deans were also asked to consider what other changes might be needed in order to address the anticipated changes.

Follow up consultation occurred with 51 delegates to the 29th Australian Association of Engineering Education annual conference held in Hamilton, New Zealand. Delegates were presented with a summary of views from the ACED workshop and an indication of the level of agreement and/or disagreement with these views was sought. Delegates were then asked for their views on curriculum and other issues needed to address the predicted changes and the implications for them as engineering educators.

Key themes emerging from these consultations and the literature review were identified concerning the future nature of professional engineering work, anticipated changes in expectations of future graduates' knowledge, skills and attributes, priorities for engineering education and changes needed if engineering education is to deliver on these needs.

The Nature of Future Professional Engineering Work

There was strong agreement that 'technical expertise' will continue to be expected of professional engineers although no clear picture emerged on what this means and how this could be defined.

Engineering thinking that is closely aligned with the Engineering Habits of Mind (EHOM): systems thinking, adapting, problem finding, creative problem-solving, visualising, and improving (along with more general learning habits of mind as represented in the following Figure 1 that was developed by the Royal Academy of Engineering (2014)) also emerged as a distinctive and desirable component of engineering expertise.

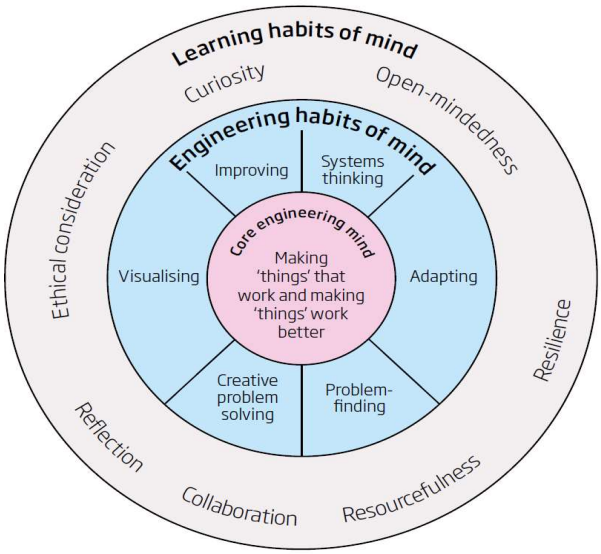

Figure 1: Engineering Habits of Mind (Royal Academy of Engineering (2014) p2)

Strong agreement also emerged on the following characteristics of future engineering work. Thought leader quotes are included in *italics*.

1. **There will be a greater diversity of engineering work**
2. **The role/nature of engineering disciplines is contested**: Some believe disciplines will still be relevant, graduate recruitment will be based on discipline and there will always be specialisation as indicated by the following thought leader quotes.

> *"'as time goes on we're seeing more niche and niche roles in engineering…I know if I get an xxxx engineer from A they're proficient in mechanical engineering skills, whilst if I went to B they've got electrical engineering. So I pick my juniors appropriately according to that."*
>
> *"will probably need a larger cohort of very in-depth technical specialists around not just disciplines but areas of activity, say water, or even water is too broad, but that suite of supporting technology experts will perhaps be more important,"*

Others expressed a view that current discipline-based boundaries are likely to become fuzzier, less rigid, and/or more porous with some disappearing completely through being subsumed into the modus operandi of other more generalist engineering disciplines and systems engineering approaches

"there's less importance on discipline. We started to recognise the complementarity of certain engineering disciplines which are more closely aligned."

"Discipline is not important anymore….there's less importance on discipline …they've got the skill, they've got the engineering mind. It's just a matter of applying it in a different context and assisting the employee through that."

3. **There are predictions of an increasing focus on systems and integration**, driven by the needs of increasingly complex and multi-disciplinary work.
4. **Digital tools will be pervasive and change the nature of engineering work and the engineering workforce.** Rapid advances in digital technologies and tools available to support engineering work will lead to automation of repetitive and readily codified tasks, including calculation and standard detailed design tasks and the subsequent hollowing out or disappearance of such work.

   "the kind of engineers who have got template solutions to known problems, we'll see less of that, because that work will be done by machine"

   "there will be engineers who deal with only technical problems, where you basically can be pretty isolated and don't have much interaction with people. They will be a minority"
5. **Professional engineering will increasingly be more about creativity.** Augmentation of human capabilities via digital tools and technologies is predicted to shift the emphasis on engineering work towards more creative endeavours.

   "we have seen the change on multiple fronts. One is the whole notion of impact of digitisation and automation of the work we do which has shown a transformation on the workforce and also the activities that a workforce does…..Some of it leads to speed of productivity and gain. But the other is the time to be more creative and actually bring the creative engineering elements to the work, which is actually where engineering started in my view. It was more about the creative process than I guess doing calculations fast, which is now being done by machine."

   "the engineer of the future will need to be able to take their skill set and mix it with the skill set of others to make connections that are creative and useful."
6. **Engineering work will be increasingly complex, multidisciplinary and will privilege life cycle and societal considerations**. Engineering practice will increasingly involve collaboration and interaction with other disciplines whether it be technology driven 'Smart-agriculture' and use of big data to improve farming productivity, or the application of robotics in health care, or in cross functional teams developing new software products.

   "we don't have predefined problems as much as we used to have. They tend to be more complex these days, multidimensional, they tend to have a social element, it's got big environmental elements"

   "most people who have engineering qualifications are going to be working on problems that will have a people social dimension to them and would definitely require them to work with other people in teams and require them to be effective communicators"

   "engineering is becoming quite complex in the expectations…. professional engineers will be the people that will be required to sign off on complex projects. And they will need to be quite sophisticated in their capacity to both understand the technical but also to rise above it to look at the context"
7. **Problem finding and stakeholder engagement will increase.** There will be greater engagement with stakeholders in identifying problems that are worth solving. Professional engineers will deal with scoping of issues and establishing strategic direction, as well as being a problem solver and technical solution provider.

   "we are moving from what was largely problem solving to also the problem finding domain….. we don't have predefined problems as much as we used to have….there is a lot more

engagement by stakeholders on the work we do, we have the opportunity and responsibility to engage with them in identifying what is the problem worth solving, and then we bring our technical skills to solve them".

8. **Trust and social license to operate will be more important**. Professional engineering work of the future will be far more connected to people, community understanding, trust and social license, and require engineers to communicate work more effectively. The availability of and ready access to information means everyone will have access to specialised knowledge, not just engineers. Transparency of decisions and actions will be more important and there will be greater public accountability. Social licence may be increasingly devolved from companies to individuals. The impact on society of engineering work will be increasingly scrutinised with risks and benefits needing to be evaluated and explained.

   "There is far more expectation that engineers do move beyond their technical competence and that they can look at the consequences of, foreshadow the consequences of, and think about how their responses and their outcomes will meet a range of needs that are beyond what would have been considered applicable in the past."

9. **Engineering practice will be more globalised** involving transnational sharing of work, recruitment from global talent pools, greater mobility of people, and global engineering project teams.

   "the profession has also changed in the way we work in terms of the mobility of people, in terms of globalisation and how people work across geography, enabled by technology. We can share information very easily these days, work together across the globe and can have our teams working together on the same project at the same time. So there's that aspect of professional engineers work that has changed."

Key messages about change in engineering education

"We could just let education drift on and there will be some changes that will meet the needs of the future, but it probably will be too slow for the challenges that are heading our way"

Notwithstanding the limited extent of consultation undertaken to date as part of this study, clear messages emerged about what it means to think like an engineer, forthcoming changes in the nature of professional engineering work, and the need for corresponding changes in the education of future engineers.

Technical skills and expertise will continue to be expected. However, there are conflicting views on the future expectations and requirements relating to specialisation versus breadth, and the role, if any, of engineering disciplines.

The diversity of thought leaders' views on these issues necessitates their further exploration with a much broader range of stakeholders including recent graduates and employers. Preliminary work has begun on canvassing the views of recent graduates.

Despite these uncertainties there appears to be a significant level of agreement on the following five points.

1. **A greater diversity of educational outcomes will be required** necessitating an increasingly diverse range and scope of programs, and pathways that are capable of attracting and retaining a more diverse cohort of students. This raises many questions, including:
   - Could an engineering education be reimagined as a 'new liberal arts degree' with a problem finding/solving and design focus, mathematics and science foundations, and the development of engineering thinking and judgment while fostering the capacity for lifelong learning?
   - Will double degrees and/or micro credentials contribute more towards meeting future education requirements? What are the implications for the engineering component of such combinations?

More work is needed to investigate options to further diversify the Australian engineering education landscape.

2. **T-shaped outcomes will be increasingly valued**. However establishing a clearer definition of expectations of technical expertise and the broader capabilities of future engineers will require additional investigation. Figure 2 has been adapted from a presentation by Dr Kourosh Kayvani on Directions for Engineering Education: the Engineer of 2035 at the 2017 AAEE conference and summarises many of the changes and contexts for future engineers that were identified in this study. Validation of this framework and a more detailed understanding of this mapping should be pursued through more extensive consultation across a broader range of stakeholders including recent graduates and employers in a range of enterprises and sectors.
3. **Curriculum contexts and pedagogies will need to change** in order to deliver these requirements. Greater use of open-ended problems, and stronger engagement with industry and community is needed. Problem finding as well as problem solving will be required. Pedagogies that nurture the development of engineering habits of mind as well as more general learning habits of mind are required.
4. **The impact of education providers' organisational structure and culture on effecting such changes will need careful consideration**. The engineering education system will need to consider how to ensure an appropriate emphasis on changing needs such as systems engineering and collaboration at the interfaces between engineering and other areas of professional expertise. The development of technical and professional skills supporting collaborative, inter-disciplinary team work and work outside conventional engineering roles appears likely to be a more important part of an engineering education for the future.
5. **New kinds of engineering educators will be needed** who are more practice-oriented, better able to engage with and inspire students, and better able to use appropriate pedagogies and adapt to the broadening requirements of engineering education.

Although consultation was framed around ascertaining the anticipated needs in 2035 a strong message has emerged that many of these outcomes are needed now and urgent action is needed to address these requirements.

Recommendations for further work

The scoping study makes three detailed recommendations for further work to validate and elaborate on these initial findings, and to explore solutions within the engineering education system. These are summarised here.

Recommendation 1 - Knowledge, Skills and Attributes of future Graduate Engineers

Extend consultation with a broader range of stakeholders, including more employers, and surveys of students and recent graduates, to validate and supplement the findings of the scoping study, and set educational priorities for the universities.

Recommendation 2 - Engineering Education Programs

Prepare a detailed critique of applicable developments in engineering education, referencing national and international best practice, and emerging educational models within the higher education sector.

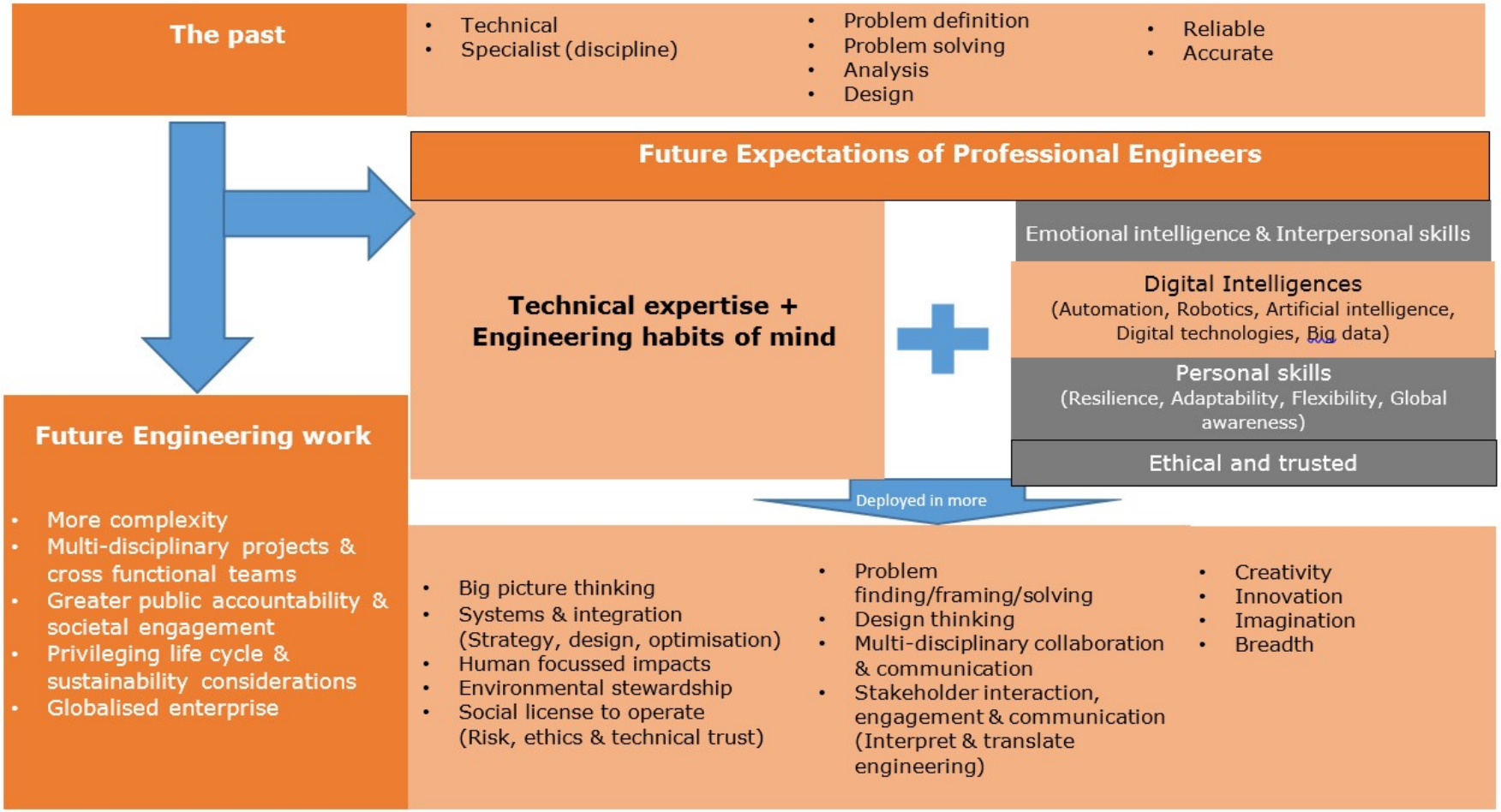

Figure 2: Changes in the professional engineering landscape

Investigation should include new models for engineering education to meet the extended range of learning targets. These could include imagining engineering as a 'new liberal arts degree', examining futures for double degrees and/or micro-credentials and considering whether the 4-year Bachelor of Engineering (Honours) might be superseded as the dominant education pathway.

Recommendation 3 - Engineering Educators

Establish both the existing engineering educator workforce profile and the desired profile for the future workforce that can deliver the required knowledge, skills and attributes.

This will be achieved by surveys of the existing educator workforce, and gap analysis. In addition, a desktop review of models that may be used to successfully facilitate engagement of engineering educators with a broader range of experience in engineering practice outside academic environments will be explored.

The full report also includes recommendations for complementary work, ideally in partnership with Engineers Australia and other national bodies, on improving the public profile and awareness of engineering in Australia; quantifying the contribution of engineering to Australia's economy; and systematically charting the career experiences of graduate engineers.

The full scoping study report is available at www.aced.edu.au

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Acknowledgements

This work was undertaken on behalf of and sponsored by the Australian Council of Engineering Deans (ACED). The membership of ACED is a senior academic representative of each of the 35 Australian universities that provide professional engineering degrees accredited by Engineers Australia. ACED's mission is to promote and advance engineering education, research and scholarship on behalf of the Australian higher education system. Figure 2 is adapted from a presentation by Dr Kourosh Kayvani FTSE, at the Australasian Association of Engineering Education Conference, 2017.

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