AUSTRALIAN COUNCIL OF ENGINEERING DEANS

ENGINEERING FUTURES 2035:

A scoping study

ABSTRACT

This scoping study explores the knowledge, skills and attributes of professional engineers required to meet anticipated changes in the nature of engineering work in Australia in the year 2035. It explores potential approaches to engineering education that prepares graduates and makes recommendations for further detailed investigation.

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Foreword

Last century workplace changes, particularly through mechanisation and robotics, had large impacts upon unskilled labour. The next changes that are already with us, including the use of artificial intelligence, data analysis of large data sets and the internet of things have the potential to profoundly influence professional work over the next twenty years. Professional engineering work will not be immune from these changes.

What then are the skills required of a professional engineer operating in this new environment? Will there be less emphasis on technical skills when routine calculations are performed using intelligent machine algorithms? Will a professional engineer be required to work more at the front-end problem definition and in multi-disciplinary teams and with more representatives of the communities we serve, requiring greater and deeper communication skills? How are these skills best obtained? More fundamentally, how do engineers think and how is that thinking different from other professionals?

The work of this project sought answers to these and other questions. It has been 10 years since the last review of engineering education, and it is timely to take stock of where we have arrived and where we need to go next. I wish to emphasise that this project is not critical of the current state of engineering education. Australia has an enviable record of producing high quality engineering graduates who have contributed to the infrastructure, energy, health, environment, and wealth of many nations. However, as stated, there are seismic shifts in practice occurring that demand consideration of the future engineering professional skill set now.

This report was commissioned by the Australian Council of Engineering Deans and the very able committee consisted of (in alphabetical order):

- Professor Ian Burnett
- Ms Bernadette Foley
- Dr Tom Goldfinch
- Emeritus Professor Doug Hargreaves AM
- Emeritus Professor Robin King
- Professor Julia Lamborn
- Dr Mark Symes
- Professor John Wilson

Emeritus Professor Caroline Crosthwaite did much of the background work and wrote drafts of this report, and we are all indebted to her hard work and dedication.

The committee wishes to thank all the people interviewed for this report and appreciate their giving of their valuable time. The committee is also grateful for the guidance received from the Australian Council of Engineering Deans.

Emeritus Professor Peter L Lee FTSE, FIEAust.

Chair, Steering Committee

Executive Summary

This scoping study has been commissioned by the Australian Council of Engineering Dean (ACED) to consider the changing nature of professional engineering practice and the implications for engineering education in Australia. It is intended to inform leaders of engineering education programs and the engineering education community on significant drivers of change in professional engineering roles and anticipate the impacts on these changes on the expectations of graduates of professional engineering programs in the year 2035. The year 2035 has been chosen as the horizon for this work as it represents generational turnover in the formal education timeline: commencing school students of 2018 will be graduating from University in 2035. Although this study is limited to consideration of the professional engineer, the distinction between complementary roles, responsibilities and education of professional engineers and engineering technologists and associate members of the engineering team has also been identified for further consideration in any future work.

The scoping study was carried out under the direction of a panel of engineering education leaders drawn from key stakeholder organisations in the Australian engineering education community. A critical element of this work has been to engage with key stakeholders, to capture their views and ensure that consideration of a representative range of inputs informs the outcomes and recommendations of this project. Wherever possible quotes are used in the report to illustrate thought leader thinking. The scope and methodology are described in Section 1.

Background studies have been used to review the nature of professional engineering practice and its value to Australia. These are presented in Section 2.

Drivers of change include rapid advances in a range of technologies, increasing globalisation, changes in work, and changing societal expectations and evolving human needs. These are reviewed in Section 3.

Consultation with thought leaders representing a range of business and community interests, and engineering educators are used to canvas key stakeholders' views on what such changes mean for the future of professional engineering work in Australia. The findings on the anticipated nature of future engineering work and the workforce are presented in Section 4.

Section 5 reviews work on the distinctive characteristics of engineering thinking and the anticipated knowledge, skills and attributes that will be expected of professional engineering graduates entering the workforce are outlined in Section 6.

There was a consistent message that although Australia's engineering education system has served the country well in the past, it must change if it is to meet future expectations and needs. The rapid pace of change is such that the engineering education system can no longer rely on incremental evolutionary change; urgent action is needed to address the challenges arising from these changes.

There will be a greater diversity of engineering work. The significance of engineering disciplines and specialisations is contested although there was considerable agreement that: technical expertise will be expected ; holistic and systems approaches will be increasingly valued; engineering work will be increasingly complex, multidisciplinary and will privilege life cycle and societal considerations; expectations around trust and social license to operate will increase; problem finding in conjunction with stakeholders will be increasingly important; and engineering practice will increasingly involve collaborations and interactions across an ever growing range of constituencies. Digital tools will be pervasive and enable a shift toward more creative work.

Technical skills, big picture and systems thinking, creative problem finding, definition and solving skills, collaboration, interaction and engagement skills, curiosity, adaptability, innovation, resilience and enterprise skills, digital intelligence, and emotional intelligence will be expected.

The predicted increase in the diversity of engineering work and expectations of graduates will necessitate a greater diversity of educational outcomes, programs and pathways in the Australian engineering education system. It is desirable that diversification also includes greater gender, ethic, and cognitive diversity in the engineering student and graduate cohorts. Along with increasing diversity within engineering, it is likely that Australia will need to produce more graduates with engineering skills to offset the current heavy reliance on immigration.

Thought leaders' views on priorities for change in engineering education to address future needs and deliver on the required knowledge, skills and attributes are covered in Section 7 and include the need for organisational structures and cultures that enable and encourage a more humanised/societal focus in engineering education programs; the breaking down of silos to deliver better integrated curricula that contextualise and emphasise development of professional skills delivering a broader range of outcomes; and changes in curriculum context and pedagogies that involve collaborative open–ended problem finding and problem solving in multidisciplinary project teams. The engineering educator workforce has also been identified as a crucial area in need of change to enable greater stronger external links into engineering education programs and delivery of the broader range of programs and program outcomes.

Selected findings from other reviews on emerging trends, changes and future needs in engineering education, and international examples of recent developments in engineering education are also considered in Section 7.

An overview of the existing engineering education landscape and recent developments in Australia is provided in Section 8.

The report concludes in Section 9 by identifying key changes needed in engineering education for the future as embracing and delivering greater diversity of education programs and program outcomes, including a more humanised focus, big picture thinking, problem finding as well as problem definition and solving, creativity and innovation, digital intelligence and broader outcomes. Changing curricula, pedagogies and new kinds of engineering educators will also be needed.

Section 10 makes three recommendations for further work for which ACED would be the principal sponsor. These are framed in terms of establishing the knowledge, skills and attributes expected of graduate engineers in 2035 (Recommendation 1), growing the diversity of engineering education programs (Recommendation 2), and ensuring greater diversity in the engineering educator workforce (Recommendation 3). These three recommendations provide the framework for follow up work that would provide guidance to stakeholders on driving change in engineering education to meet the future needs. The final report would be a call to action for change in engineering education of professional engineers in Australia and address a broad range of stakeholders including government, professional engineering organisations and education providers, and the community.

Section 10 also makes three more recommendations that ACED may wish to pursue with other organisations as the principal sponsor.

Recommendations for Engineering Futures 2035 Stage 2

Stage 2 Recommendation 1 (Graduate Engineers Knowledge, Skills and Attributes)

Extend consultation to explore the perspectives of a broader range of stakeholders to add to and validate the outcomes of the scoping study and in particular the anticipated knowledge, skills and attributes expected of graduate engineers in 2035 and educational priorities for universities contributing to development of these outcomes by:

i. Undertaking further consultation with more industry and government employers and end users to ascertain the nature of their future needs for and expectations of graduate professional engineers. The distinction between professional engineers and other members of the engineering team should also be explored. A challenge will be to cover adequately emerging areas, start-ups and SMEs as well as traditional engineering industries. National engineering research institutes and centres (CSIRO, D61, ANSTO, DSTG, and CRCs) should be included. ACED members' industry advisory committees must also be involved.
ii. Undertaking a national survey of recent engineering graduates to explore their employment contexts, the transition from education into work, and career expectations and ambitions. Graduates view on essential knowledge, skills and attributes needed for their current employment and priorities for change in engineering education that would better meet both their current employment needs and future career aspirations should be canvassed.
iii. Undertaking a national survey of final year engineering students (both bachelor and accredited masters) to explore their educational background, career expectations and ambitions, and perceptions of their programs and their transition to the world of work within and outside engineering.
iv. Undertaking a national survey of students commencing engineering degrees (including the engineering studies streams at The University of Melbourne and University of Western Australia) to understand their background, motivation, expectations and ambitions with reference to choosing to study engineering.
v. Undertaking a detailed national study of equity and diversity in engineering education and graduates' early careers. The increasing diversity of pathways into engineering will need to be examined in detail. Understanding the features in school education and career advice that enable (and inhibit) greater diversity should be investigated.
vi. Surveying Deans of Science, Deans of Information and Communications Technology (ACDICT), Australian Business Deans Council (ABDC) and leaders of various Employability Initiatives on future directions to establish potential synergies and alliances in future education developments.

Confirm and extend the findings of the scoping study to inform further work proposed in recommendations 2 and 3.

Stage 2 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 by:

i. Undertaking consultation with selected engineering educators on new and emerging engineering education programs to provide guidelines and exemplars that may be relevant to the delivery of the range of knowledge, skills and attributes required.

ii. Undertaking a desktop review of global best and emerging practice to develop guidelines and exemplars of new and renewed engineering education programs that can deliver the range of knowledge, skills and attributes required.

Educational philosophy, program structures and pathways, curriculum and pedagogy, assessment, and enabling people, processes and resources would be considered.

Areas of investigation should include

a) Models for the expansion of the current narrow range of program architectures that underpin entry to practice programs available in Australia. Could an engineering education be reimagined as a ‘new liberal arts degree’ with a problem solving and design focus, mathematics and science foundations, and the development of engineering thinking, judgment and capacity for lifelong learning? What role will double degrees and/or micro credentials play in meeting future education requirements? Should the 4 year Bachelor of Engineering (Honours) be superseded as the dominant education pathway?
b) Approaches emphasising the human dimensions of engineering so that graduates are equipped with a greater understanding and awareness of the potential impact of engineering practice, both good and bad, on human, societal, and environmental needs.
c) Design and implementation of better integrated curriculum employing systems approaches that develop enterprise skills, and interaction and engagement skills in professional practice contexts.
d) Embedding more extensive cross disciplinary, cross institutional and external industry and community engagement in engineering education programs.
e) Use of more experimentation, collaborative pedagogies and open-ended projects/problems in engineering programs.

Embedded curriculum-based practice and student experience is to be the primary focus of this work with particular attention paid to scalability. Exemplars of extracurricular programs could also be provided. Appendix 8 provides further details of a proposed framework.

Recommendations on action by key stakeholders and change management issues, including possible constraints and impediments that will need to be addressed in the Australian context will be developed.

<u>Stage 2 Recommendation 3 (Engineering Educators)</u>

i. Establish the existing engineering educator workforce profiles and desired profile for the engineering educator workforce that can deliver on the required knowledge, skills and attributes by:
   a. Undertaking a survey of the existing engineering educator workforce, to analyse their knowledge, skills and attributes, and
   b. Performing a gap analysis against that required to effect curriculum and pedagogic renewal in future engineering education programs.
ii. Undertake 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. This includes practitioners who can engage with students in innovation, entrepreneurship, and design focussed learning activities and assessments.

iii. Propose solutions to modify the engineering educator workforce as indicated by the gap analysis and informed by the desktop review.

Recommendations for other work

Recommendation 1: ACED continues to engage with and endorse organisations and programs working to improve the public profile and awareness of engineering and its contribution to society and human well-being. The outcomes of any further work on this review that are undertaken by ACED should be promulgated by revising key messages delivered through such work. These should include a stronger emphasis on 'humanising engineering' and using societal impact in relation to improving public perceptions and understanding of engineering.

Recommendation 2: ACED explore with Engineers Australia, ATSE and the Office of the Chief Scientist their interest in undertaking an investigation into the value of engineering to the Australian economy and quantifying its potential to contribute to the nation's future economic growth and prosperity.

Recommendation 3: ACED engages with government, EA and other industry stakeholders to explore their interest in undertaking detailed investigation of the employment experiences of recent engineering graduates that can be used to inform both future engineering workforce and education planning projections and in particular the recalibration of the optimum numbers and diversity of professional engineering graduates entering the Australian workforce following completion of a program of education in Australia.

Contents

1. Introduction

The world is changing rapidly. Globalisation, the growth and development of new technologies, and society's evolving and diverging needs are presenting humankind with new challenges and opportunities for the way we will work and live in the future. The Australian Council of Engineering Deans (ACED) is undertaking a review to inform ACED and its stakeholders on these issues and their impact on future directions for professional engineering work in Australia and the Australian engineering education system that prepares graduates for this work. It is 11 years since the last review of engineering education in Australia. ACED believes that another Review is timely. This Review is looking forward to the year 2035 and focusses primarily on:

1. key drivers of change that are expected to impact future professional engineering practice;
2. anticipated changes in the future characteristics of professional engineering roles and workforce;
3. anticipated expectations of graduate professional engineers seeking to enter the workforce;
4. implications of these changes for education programs that will produce these graduates.

This scoping study explores these themes and makes a set of recommendations on further work that could be done to identify changes that may be required in engineering education to address these needs. The outcomes of the Review are intended to assist the Australian engineering education community to lead change, as well as react to emerging factors.

This work was carried out under the direction of a Steering Committee with membership drawn from ACED, the Engineering Associate Deans (Learning and Teaching) Network (ADLT), Engineers Australia (EA) and the Australasian Association for Engineering Education (AAEE). The Review draws on consultation with a range of stakeholders involved in professional engineering practice and professional engineering education in Australia. It also leverages other related work being done nationally and internationally.

1.1 Scope

Although engineering is a global profession, each nation has its own engineering contexts. This study focusses on engineering practice and education in Australia and its potential to contribute to the future Australian economy and society, albeit in a global context. In Australia, the engineering team comprises of three groups, Professional Engineers, Engineering Technologists and Engineering Associates. These are differentiated initially based on education qualifications[1] and the various associated standards used for accreditation with Engineers Australia (EA)[2]. This study considers only the role of the Professional Engineer and education programs providing entry to practice as a Professional Engineer, although the distinction between the roles and responsibilities of professional engineers and engineering technologists in the workforce is also considered. Australia is a member of the International Engineering Alliance and a signatory to the Washington Accord. As such, a minimum of the equivalent of 4 years of full-time study in a Bachelor of Engineering (honours) degree is currently required for entry to practice programs.

This Review is a preliminary investigation and scoping study that uses other work as the basis for framing conversations and consultations held with a range of stakeholders in order to explore the future of professional engineering work and education in Australia and develop a set of

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[1] EA Accreditation Principles https://www.engineersaustralia.org.au/sites/default/files/2019-02/AMS-POL-01_Accreditation_Principles_v2.0.pdf

[2] EA Stage 1 competency standards for professional engineer, engineering technologist and engineering associate available at https://www.engineersaustralia.org.au/About-Us/Accreditation/AMS-2019

recommendations for further work. Although the primary focus of this work is concerned with professional engineering qualities it also reviews recent reports and quantitative data on the Australian engineering workforce and considers the future implications for the engineering education system.

1.2 Methodology

The Review draws on several published sources. These include: reports and statistics from Australian and state governments, and Engineers Australia; reviews, reports and papers from engineering organisations in other countries including the USA's National Academy of Engineering (NAE), the UK's Royal Academy of Engineering (RAE), and Europe's Society for Engineering Education (SEFI) as well as the Australasian Association for Engineering Education (AAEE); and publications of international organisations including the United Nations (UN) and World Economic Forum (WEF) and various Australian corporate, not for profit, and education organisations. Presentations made at the 2018 Conference of the ASEAN Federation of Engineering Organisations (CAFEO) and the 2018 Australian Engineering Conference (AEC) are also used. Input from these sources was used to frame interviews and consultation with stakeholders to confirm and investigate literature findings and explore possible professional engineering futures in the Australian context.

Consultations with a range of leaders of engineering, business and community organisations representing a range of stakeholders was undertaken using semi-structured 1-hour interviews to explore their views 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. Quotes from the thought leader interviews are *'indicated in italics'* with anonymised attribution (TLx) and used in various sections of the report to illustrate these themes. Eight interviews were completed. The list of thought leaders interviewed is provided in Appendix 1.

Consultation was also undertaken with the Australian Council of Engineering Deans via round table discussion to collect member views on anticipated changes looking forward to 2035 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 workshop consultation occurred with 51 delegates to the 29th Australian Association of Engineering Education annual conference held in Hamilton, New Zealand on December 10th, 2018. 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 looking forward to 2035 on curriculum and other changes needed to address the predicted changes and the implications for them as engineering educators.

Convergence of key themes emerging from these consultations is identified and used to formulate the recommendations for further work. The recommendations are divided into two categories: the first being for work that ACED may wish to pursue as principal sponsor to follow up on the findings of this study, and the second being for work that ACED may encourage other stakeholders to pursue.

2. What is engineering and why it matters?

> *'Engineering is about the creation or application of technology to produce goods and services for the community. It involves finding solutions to human and environmental problems while making things for people to use. Engineers are involved in the research, design, production, operation and maintenance of many things that we take for granted in our everyday lives.'*[3]

Modern engineering practice lies at the interfaces between science and technology and human needs. Engineering has profound impacts, good and bad, on human well-being, the global economy and environmental health. Engineering has been described as a '*creative, practical activity*'[4] and '*forward thinking*'[5]. Professional engineering is also associated with '*skills to define and solve problems elegantly and cost effectively, the ability to design innovation and work well with others*'[6].

Engineering in Australia is generally considered to be based around five traditional areas of practice; civil, chemical, electrical, mechanical and mining engineering. Within each of these broad areas there are many specialisations. For instance, civil engineers may work as specialists in structural, water, geotechnical, construction, or traffic engineering. Newer disciplines such as computer systems, software, and mechatronic engineering have emerged in recent years and are associated with the growth of computing power and digital technologies. Specialisations in areas such as aerospace, biomedical, humanitarian, nano-materials, and renewable energy engineering have also emerged. Systems engineering adopts an interdisciplinary approach that transcends individual disciplines, thereby facilitating the optimisation of the design, analysis and management of complex systems and projects that are becoming more prevalent in today's society. Modern engineering encompasses a broader range than ever before of areas of practice, specialisations and interfaces with other disciplines and professions.

A functioning society and the economic prosperity of developed countries such as Australia rely heavily on outputs of engineering work across a wide range of applications. This includes essential infrastructure and services such as power, water, housing, transport and communications that underpin everyday life. The 2019 World Economic League Table report estimates

> '*that global construction spending in 2018 was $11,448 billions which represented 13.5% of global GDP. This share, which is already one of the highest on record other than at times of post-war recovery, is likely to edge upwards for a range of reasons. First, there is a wide range of mega projects underway starting with the Chinese Belt and Road initiative. These mega projects account for an increasing proportion of world GDP. Second, in many economies there is an infrastructure backlog.'*[7]

In Australia the development of new infrastructure, such as the National Broadband Network the proposed Snowy Hydro 2 power scheme, the Internet of Things, as well as operations in a broad range of industries and businesses recognised as traditional engineering domains ranging from construction, manufacturing and mining to waste management all draw on engineering practice. Among the OECD countries Australia's economy is most like Canada's in that while resources,

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[3] Engineers Australia. https://www.engineersaustralia.org.au/sites/default/files/resources/Public%20Affairs/2018/EA%20-%20About%20us%20and%20fact%20sheet_0.pdf

[4] The Universe of Engineering: A call to action. Royal Academy of Engineering (October 2014) https://www.raeng.org.uk/publications/reports/the-universe-of-engineering

[5] Changing the Conversation: Messages for Improving Public Understanding of Engineering. National Academy of Engineering (2008)

[6] Engineering Workforce Review, Australian Workforce and Productivity Agency, https://docs.education.gov.au/system/files/doc/other/engineering-workforce-study-june-2014.pdf

[7] World Economic League Table Report 2019, https://cebr.com/welt-2019/

manufacturing and agriculture are important, exports in services account for more than 60% of the economic base of both countries. Engineering now contributes to the provision of services not traditionally associated with engineering: these include technology enabled connected healthcare and aged care solutions, and 'smart' agriculture.

2.1 Public perceptions of engineering

The diverse nature and value of professional engineering practice and its value to the economy and society is not well understood by the general community. This impacts the status in the community and their perceptions of the profession[8]. Stereotypes based on traditional engineering roles and sectors do not reflect the roles and impacts of engineering in areas such as sustainability, environmental stewardship, medical technology and pharmaceuticals, financial systems, security, and entertainment and media. Nor do they recognise the role engineering will play in shaping our global future. Many of the United Nations 17 Sustainable Development Goals[9] are dependent on the work of engineers. Despite various attempts to define engineering and calls to improve community understanding of engineering from governments, engineering professional bodies and education providers, public perceptions of and attitudes to engineering continues to be a major issue for the profession in Australia and other western countries [10, 11]. The 1996 review of engineering education in Australia[12] made the following recommendation:

> '*School and community liaison must be enhanced so that more students choose engineering*.'

The next national review of engineering education in Australia in 2008[13] made a similar recommendation.

> '*Raise the public perception of engineering, including within primary and secondary schools, by increasing the visibility of the innovative and creative nature of engineering and the range of engineering occupations that contribute to Australia's prosperity, security, health and environment*.'

In the USA the National Academy of Engineering (NAE) review in 2005 on 'Educating the Engineer of 2020'[14] made the following recommendation:

> *'The engineering education establishment should participate in efforts to improve public understanding of engineering and the technology literacy of the public and efforts to improve math, science, and engineering education at the K-12 level.'*

In the United Kingdom the Royal Academy of Engineering (RAE) in its 2014 report 'The Universe of Engineering A call to action'[15] also recommended:

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[8] Engineering Workforce Review, Australian Workforce and Productivity Agency, https://docs.education.gov.au/system/files/doc/other/engineering-workforce-study-june-2014.pdf

[9] Sustainable Development Goals https://www.un.org/sustainabledevelopment/sustainable-development-goals/

[10] UK STEM Education Landscape. Royal Academy of Engineering (May 2016) https://www.raeng.org.uk/publications/reports/uk-stem-education-landscape

[11] National Academy of Engineering. 2008. *Changing the Conversation: Messages for Improving Public Understanding of Engineering*. Washington, DC: The National Academies Press. https://doi.org/10.17226/12187

[12] Changing the Culture: Engineering Education into the Future, 1996, IEAust

[13] Addressing the supply and quality of engineering graduates for the new century , Robin King Carrick Institute (March 2008)

[14] Educating the Engineer of 2020: Adapting Engineering Education to the New Century
Committee on the Engineer of 2020 ; Phase II ; Committee on Engineering Education ; National Academy of Engineering;14 October 2005

[15] The Universe of Engineering: A call to action. Royal Academy of Engineering (October 2014) https://www.raeng.org.uk/publications/reports/the-universe-of-engineering

'The engineering community needs to develop a dynamic inspiring, continually evolving set of images and messaging for a wide audience.'

The UK's '*This is Engineering*' initiative[16] is a multi-year, multi-organisation response to this call.

2.1.1 Outreach activities and impact

Resources and outreach programs such as the Australian Government STARportal[17] provided through the Office of the Chief Scientist, the Australian Academy of Technology and Engineering sponsored STELR (**S**cience and **T**echnology **E**ducation **L**everaging **R**elevance)[18], and the Power of Engineering program[19] and a range of university outreach programs, including Women in Engineering programs targeting the gender imbalance, are important initiatives for engaging with schools and students to try to improve the understanding and appreciation of engineering. In the UK the '*This is Engineering*' campaign is attempting to provide better mentoring to school children, emphasising creativity and problem solving and helping people[20]. In the USA the National Academy of Engineering is doing similar work to understand and address key messages for and barriers to improving public understanding of engineering[21].

Despite such programs, public perceptions and attitudes towards engineering continue to be of concern in these countries. The Royal Academy of Engineering in the UK reported in 2014[22] that

..*'fifteen years on from the original Universe of Engineering report, the central role of engineering in society is still not evident to the public at large. The lack of awareness of the real nature of engineering has a serious consequence – young people and their influencers have outdated views of engineering, and as such are not pursuing careers in our profession*.'

In Australia, interest in engineering careers appears to be waning. In 2017 engineering programs accounted for only 5.2% of national commencing bachelor degree students, the lowest proportion on record[23].

See Section 10.2 Recommendation 1.

2.2 Engineering and economic development

2.2.1 Global perspectives

Around the world engineering plays a key role in supporting national economies. A global study[24] commissioned by the Royal Academy of Engineering and published in 2016 used data from 99 countries, including Australia, to investigate the value of engineering and its role in economic development using a composite Engineering Index which combines the following set of national indicators into a single value for that country.

Engineering Research
Employment in engineering-related industries

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[16] https://www.raeng.org.uk/education/this-is-engineering
[17] https://starportal.edu.au/about-star-portal
[18] STELR https://stelr.org.au/
[19] http://www.powerofengineering.org/
[20] https://www.thisisengineering.org.uk/
[21] National Academy of Engineering. 2008. *Changing the Conversation: Messages for Improving Public Understanding of Engineering*. Washington, DC: The National Academies Press. https://doi.org/10.17226/12187
[22] The Universe of Engineering: A call to action. Royal Academy of Engineering (October 2014) https://www.raeng.org.uk/publications/reports/the-universe-of-engineering
[23] Australian Engineering Education Facts – Update October 2018, Australian Council of Engineering Deans http://www.aced.edu.au/downloads/ACED%20FACTS%202018.pdf
[24] Engineering and economic growth: a global view. A report by Cebr for the Royal Academy of Engineering (Sept 2016) https://www.raeng.org.uk/publications/reports/engineering-and-economic-growth-a-global-view

Number of engineering businesses
The gender balance of engineering graduates
Wages and salaries of engineers
Human capital investment in engineering
The quality of infrastructure
The quality of digital infrastructure
Exports of engineering-related goods

Although the research revealed a lack of disaggregated and historical data for engineering across the world, the report provides evidence supporting a strongly positive and robust link between a nation's engineering strength and economic development, including gross domestic product (GDP) per capita and, investment per capita. A one-percentage point increase in the Engineering Index score is associated with a 0.85% increase in GDP per capita, suggesting that countries seeking to improve their performance in engineering, either through increasing the number of graduates, improving infrastructure or growing employment in engineering, are likely to benefit in terms of economic development. Moreover, for every additional person employed in an engineering activity, the creation of 1.74 additional jobs in the economy is projected.

Economic development, like engineering, is difficult to define precisely, but is described in this report as '*results from investment in generation of new ideas through innovation and the creation of new goods and services, the transfer of knowledge and the development of viable infrastructure*'. The report also states that '*Investment in research and development and support for entrepreneurship and innovation make a significant contribution to economic development*.' [25]

2.2.2 Australia's engineering strength in terms of economic value

According to the Cebr/RAE report[26] Australia's engineering strength in terms of economic value ranks highly: 7th overall, and 7th in the 26 CAETS (International Council of Academies of Engineering and Technological Sciences) countries that were considered. High engineering employment, strong performance in research (seven university engineering departments among the world's top 100) and the quality of digital infrastructure are the major contributors to the overall score and relatively high ranking.

The 2019 World Economic League Table Report[27] forecasts for 2033 ranks the Australian economy at number 11 out of 192 countries considered. It is currently (2019) ranked 13 with a GDP in 2018 of AU$1,769 billion. As with most developed countries, services account for the dominant share of GDP (60%) and employment (80%). However, mining, construction, manufacturing and international education are also significant contributors[28]. For instance, in 2016 - 2017 the mining industry employed 2% of Australia's workforce, but contributed 9% of added economic value[29].

In Australia in 2014 the Engineering Workforce Review[30] reported that:

> '*Engineering-related work powers many of the key industries on which Australia's current and future prosperity relies. The quality and supply of engineering skills are vital to boost the*

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[25] ibid
[26] ibid
[27] World Economic League Table Report 2019, https://cebr.com/welt-2019/
[28] World Economic League Table Report 2018, https://cebr.com/world-economic-league-table-report-2018/
[29] ABS 2017, 8155.0 – Australian Industry 2016 – 2017, and 6291.0 – Labour Force, Australia in Directors' playbook: The future of work, Australian Institute of Company Directors, October 2018 https://aicd.companydirectors.com.au/-/media/cd2/resources/advocacy/governance-leadership-centre/pdf/glc-directors-playbook-on-the-future-of-work.ashx
[30] Engineering Workforce Review, Australian Workforce and Productivity Agency, https://docs.education.gov.au/system/files/doc/other/engineering-workforce-study-june-2014.pdf

global competitiveness of Australian industries such as Mining, Construction, Manufacturing and a range of sub-sectors of the Professional, Scientific and Technical Services industries. In 2013, Mining contributed $154.5 billion, Construction contributed $116.2 billion, Manufacturing contributed $102.8 billion, and Professional, Scientific and Technical Services added $100.1 billion to the Australian economy'

The appointment in 2018 by the Victorian State Government of the State Chief Engineer, Dr Collette Burke, attests to the importance of engineering to the state's economy and future development prospects. The State of Engineering 2018 report[31] by the Victorian State Government has determined that engineering contributed $93 billion via engineering enabled industries (construction, manufacturing, ICT, utilities, engineering consulting and mining) to the Victorian state economy in 2016 – 2017 representing 25% of gross state product.

These figures show that engineering is a significant contributor to Australia's economy and has the potential to make significant contributions to future economic growth. ACED may wish to explore with organisations such as EA, the Academy of Technology and Engineering, and the Office of the Australian Chief Scientist the benefits of undertaking further work on quantifying the economic value of engineering to Australia's future.

See Section 10.2 Recommendation 2

2.3 Engineering and Innovation

Innovation is recognised as being critical to Australia's future prosperity and has been the subject of various investigations[32]. The most recent Innovation and Science Australia (ISA) review[33] claims that:

'In a world that continues to become more interconnected and complex, innovation is becoming more and more critical to national economic performance, job creation and standards of living. As the historical drivers of our productivity growth wane, we need to strengthen our capacity to generate value from our ideas and our inventiveness. Rather than being fearful of the disruption and change that technology will inevitably bring to all countries, Australians should see in these transformations the seeds of renewed growth that can sustain our enviable prosperity and quality of life.'

Innovation spans ideation to adoption and generally refers to changing or creating more effective processes, products and ideas, and thereby generating or adding value. Innovation can be diverse; ranging from development of new 'cutting edge' products, processes and services to incremental quality improvement activities, or adopting things that have been successfully tried elsewhere.

2.3.1 Australian engineering and innovation

Australian engineers have contributed to the creation of Wi-Fi technology, Google Maps, plastic banknotes, the electronic pacemaker and the bionic ear. However, the ISA review report[34] also notes that:

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[31] Victorian State of Engineering 2018 http://www.opv.vic.gov.au/Office-of-Victorian-Chief-Engineer/The-State-of-Engineering

[32] Australia 2030 CSIRO FUTURES Navigating our uncertain future May 2016 https://www.csiro.au/~/media/Do-Business/Files/Futures/FUTURES_Australia2030_Report_web.pdf?la=en&hash=9612D5EC9C7998DC660269E1BDCE4F52B512C9E7

[33] Innovation and Science Australia 2017, Australia 2030: prosperity through innovation, Australian Government, Canberra. https://www.industry.gov.au/data-and-publications/australia-2030-prosperity-through-innovation

[34] ibid

> '*Australia has also failed to capture the full value of our many inventions; the black box flight recorder, heart pacemaker, photovoltaic cells, X-ray crystallography and many others were all based on Australian research breakthroughs, but commercialised overseas*'

Innovation is also crucial in Australia responding successfully to change. For example, Geelong was hard hit by the decline in manufacturing and closure of iconic factories and large employers, such as the Ford Australia manufacturing plant and Alcoa's Point Henry smelter. However, the manufacturing base established by these industries is now the basis of the city's reinvention of itself with new work being developed in engineering, design and materials science[35].

Innovation is instrumental in the development of new and internationally competitive business. The spinoff of sonar technology developed initially for defence purposes into civilian seismic applications has created new industries and employment opportunities for Australian engineers, scientists and technicians[36].

Looking forward to 2030, the ISA report[37] suggests that future economic growth and society's well-being will be fuelled by knowledge-intensive innovation operating in global contexts.

> *'Innovation is essential to create more economic and social opportunities for Australians by 2030. With the resources investment boom easing, and our population ageing, Australia needs to find new sources of growth and improve productivity to maintain our standard of living. The biggest growth opportunities will come from knowledge-intensive companies that innovate and export, as they are the most profitable, competitive and productive. These companies will increasingly need to solve global problems at scale. When they succeed, they will make a substantial contribution to new jobs growth in Australia. This will come through both direct employment and indirect jobs throughout the economy from companies in their supply chain or in the service economy for their workers.'*

'Engineering' as a key component in realising innovation does not get an explicit mention in the ISA performance review, although there is a very strong emphasis throughout the report on the importance of 'digital' skills, as well as STEM more generally in the context of their importance in driving national performance in innovation, science and research. Internationally, the role of engineering in innovation is recognised more explicitly, for instance in the United Kingdom where it is acknowledged that:

> *'Engineering graduates and especially postgraduates provide the social networks, skills and absorptive capacity to not only 'do first-rate engineering,' but also to drive business development more generally; in most parts of the economy, engineers can be found at the heart of almost any new product development initiative.'*[38]

The ISA review presents 30 recommendations which are framed in the context of five strategic imperatives including ensuring education responds to the changing nature of work. While the recommendations on education specifically target schools and the VET sector there are also implications for higher education needing to respond to the changing nature of work. The report

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[35] https://www.industry.gov.au/data-and-publications/australia-2030-prosperity-through-innovation/transforming-opportunity-in-geelong

[36] https://www.industry.gov.au/data-and-publications/australia-2030-prosperity-through-innovation/thales-australia-partners-with-defence-science-and-technology

[37] Innovation and Science Australia 2017, Australia 2030: prosperity through innovation, Australian Government, Canberra. https://www.industry.gov.au/data-and-publications/australia-2030-prosperity-through-innovation

[38] Assessing the economic returns of engineering research and postgraduate training in the UK. Report commissioned by RAE and ESPRC. (March 2015) https://www.raeng.org.uk/publications/reports/assessing-the-economic-returns-of-engineering-rese

also identifies the lack of gender diversity in STEM being of concern with women making up less than one-third of STEM academic and research staff. This is a long-standing and significant concern for engineering.

2.4 Engineering and Societal Wellbeing

Although the outputs of engineering activity are inextricably linked with human and societal well-being and sustainability, discussion of the human/societal impacts and value of engineering is sometimes overshadowed by the economic considerations. Historically, the human-social impact of engineering work is well established. Access to clean water, sanitation, and housing contributed to an increase in human life spans and quality of life. Synthetic fertilisers increased the planet's agricultural capacity and food supplies. Electricity and refrigeration further improved human quality of life. More recently, telecommunications and the internet have delivered global connectivity and access to information. Engineering at its best is about bringing the benefits of science and technology to people and societies.

> '*engineering is so fundamental to human success and human achievement and the way the world works…. engineering is arguably one of the last remaining humanitarian professions on the planet… we not communicating it in the right way'* [39](TL1).

The Engineers Australia code of ethics[40] states:

> *'As engineering practitioners, we use our knowledge and skills for the benefit of the community to create engineering solutions for a sustainable future. In doing so, we strive to serve the community ahead of other personal or sectional interests'*.

The development and operation of infrastructure: energy, transport, communications, waste management, water supply and sanitation that underpin modern society all require engineers. Professional engineers also provide specialist knowledge to enterprises that enable them to '*achieve the high levels of productivity that underpin our standard of living*' [41].

There is an increasing emphasis on the contributions made by engineers not only to the ongoing functioning of existing societies, but also to shaping the vision and realisation of future society. In the USA the National Academy of Engineering recognises that

> *'challenges facing engineering today are not those of isolated locales, but of the planet as a whole and all the planet's people'.*

and has formulated the Engineering Grand Challenges[42] that aspire to:

> *'make the world not only a more technologically advanced and connected place, but also a more sustainable, safe, healthy, and joyous — in other words, better — place'.*

Professional engineering work is addressing such issues. The 2018 Global Engineering Congress in London was attended by thousands of engineers from around the world sharing ideas on how to address the United Nations Sustainability Goals[43]. Engineering will be central to addressing many of these including, e.g.

Affordable and clean energy,

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[39] Thought leader interview

[40] Engineers Australia Code of ethics https://www.engineersaustralia.org.au/sites/default/files/resource-files/2018-10/EA%20Code%20of%20Ethics%20Final_1.pdf

[41] James Trevelyan in Engineering Workforce Review, Australian Workforce and Productivity Agency, https://docs.education.gov.au/system/files/doc/other/engineering-workforce-study-june-2014.pdf

[42] NAE Grand Challenges for Engineering https://www.nae.edu/File.aspx?id=187214

[43] https://www.un.org/sustainabledevelopment/sustainable-development-goals/

Sustainable cities and communities,
Responsible production and consumption,
Resilient infrastructure, sustainable industrialisation and innovation
Clean water and sanitation.

In Europe, the European Society for Engineering Education (SEFI) is currently mapping the skills and competencies needed for the Engineer of 2030 to meet sustainability challenges[44]. This work is being undertaken within the framework of the Erasmus+ project "A-STEP 2030 - Attracting diverse Talent to the Engineering Professions of 2030". In Australia the Sustainable Engineering Society (SENG) is a multi-disciplinary society within Engineers Australia (EA) that provides national focus and leadership within the engineering profession for the implementation of sustainability for the benefit of Australian society[45].

The emergence of humanitarian engineering and involvement in education of organisations such as RedR Australia[46] and Engineers Without Borders Australia (EWB)[47] also attests to the growing understanding of the social impact of engineering and interest in widening this to include improving the well-being of more people and in particular marginalized people and disadvantaged communities.

Recommendation 1 in section 10.2 proposes the adoption of a stronger emphasis on 'humanising engineering', and using societal impact in relation to improving public perceptions and understanding of the value and importance of engineering work.

2.5 Australia's engineering workforce

Since 2012, around 30,000 qualified engineers have entered the Australian workforce each year with skilled migration (permanent plus temporary) providing more than 2/3 of the total while education completions by domestic students at Australian universities make up the remainder, as shown in the following Figure 1[48]. Although these figures include all members of the engineering team, professional engineers are the majority in each of the three categories. Professional engineers comprise more than 75% of the total engineering teams contributed by permanent and temporary migration and 70% of the local education completions.

The major specialisations associated with temporary migrant professional engineers in 2015 -2016 are: Software engineering (35%), Engineering managers (10%), Mechanical engineering (9%), Computer network and systems engineering (6%), Civil engineering (6%), Electrical engineering (5%) and Electronic engineering (2%). A further 19 different categories make up the remaining 29% with other engineering professionals accounting for 6.6%, Petroleum engineers 3.8%, Production and plant engineers 2.3%, and Mining engineers 1.3%. Agricultural engineeers, Naval architects, Aeronautical engineers and Materials engineers account for the smallest numbers and each are less than 0.4% of the total[49].

According to the 2016 census, there are approximately 330,000 qualified engineers (at associate, technologist and professional engineer levels) in Australia's work force. Disaggregated data for each of the three individual levels is not available. Just over half (56.3%) are employed in engineering occupations: Professional scientific and technical services employed 15% of these engineers;

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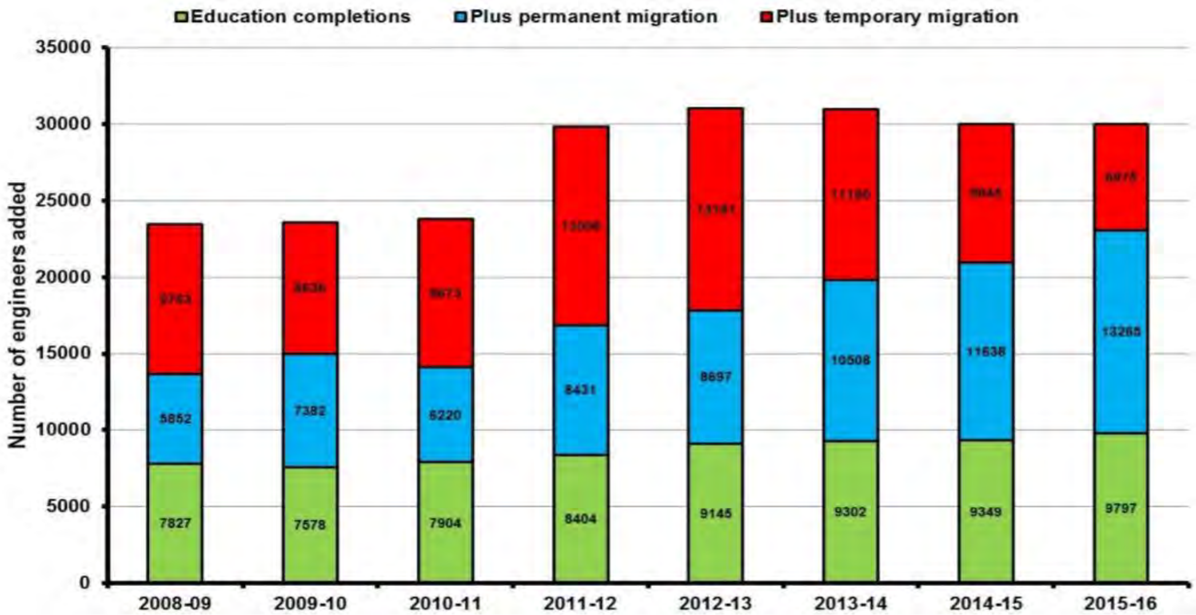
[44] Kövesi et.al. SEFI 2018 conference workshop: Skills and competencies for the Engineering of 2030 to meet sustainability challenges
[45] https://www.seng.org.au/about-us
[46] https://www.redr.org.au/about-us/who-we-are/
[47] https://www.ewb.org.au/about/whyweexist
[48] The Engineering Profession Thirteenth Edition, February 2017 https://www.engineersaustralia.org.au/Government-And-Policy/Statistics
[49] ibid

Manufacturing employed 12.5% and Construction employed 9.3%. Computer systems design accounted for 5%.[50] EA has identified seven core engineering industries in which the proportion of qualified engineers employed in engineering occupations is higher than the national average as: Professional, scientific and technical services; Mining; Electricity, gas, water and waste services; Information media and telecommunications; Construction; Public administration and safety; and Manufacturing[51].

Figure 1: Relative contributions of education completions and migration to changes in the supply of qualified engineers 2008 - 2016 [52]



Analysis by Engineers Australia of the Australian Bureau of Statistics census data for 2006, 2011 and 2016 for the top ten industries of employment for qualified engineers in Australia shows in Figure 2, that the top five industries of employment have been relatively consistent during this period. The loss of Australia's motor vehicle manufacturing industry is reflected in these figures.

Engineers are also employed in a wide range of skilled work that is not classified by the Australian Bureau of Statistics and /or the ANZSCO categories as engineering occupations.

Anecdotal evidence also suggests there are increasing numbers of engineering graduates working in small-medium enterprises and technology-intensive start-ups, many of which are using new technologies to create new products. According to the Global Startup Ecosystem Report 2018[53] both experience and formal education are important for entrepreneurs in technology start-ups and the growth sectors are part of the Third Wave of the Internet which will focus on technology driven developments in the "real world" and specific industries. Growing sectors are: Advanced manufacturing and robotics; Agtech and new food, Blockchain and artificial intelligence, software

[50] Engineers Australia https://www.engineersaustralia.org.au/sites/default/files/resources/Public%20Affairs/2018/EA%20-%20About%20us%20and%20fact%20sheet_0.pdf

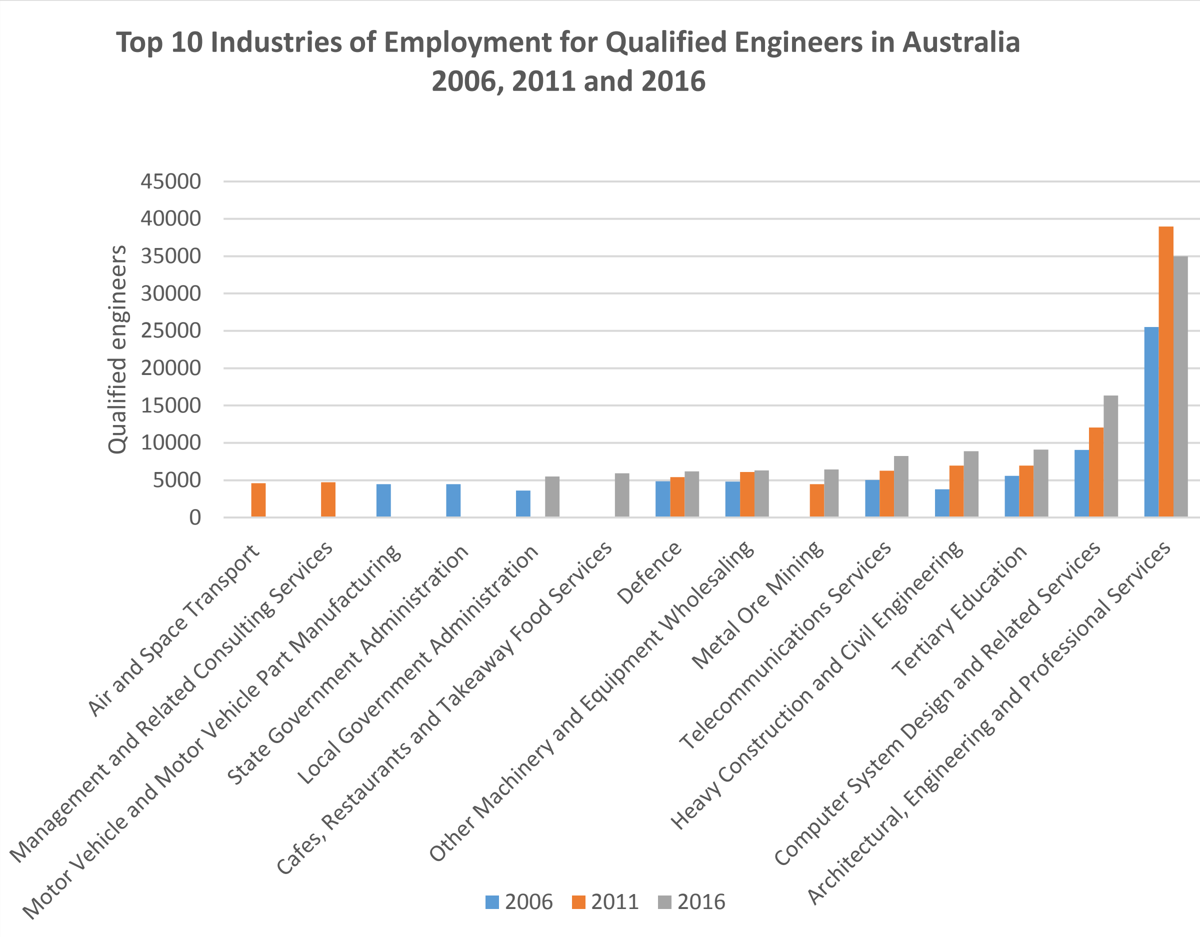
[51] Jonathon Russell EA personal communication

[52] The Engineering Profession Thirteenth Edition, February 2017 https://www.engineersaustralia.org.au/Government-And-Policy/Statistics

[53] Global Startup Ecosystem Report 2018 Succeeding in the New Era of Technology https://startupgenome.com/reports/2018/GSER-2018-v1.1.pdf

development, big data and analytics, financial services technologies (Fintech), and Australia's Mining technology services (Mintech).

Figure 2: Top industry employers of engineers in Australia[54]



Start-ups are the largest contributor to job creation in Australia with more than 1.2 million new jobs created between 2004 and 2011.[55] In 2016, 84.4 per cent of start-up founders had a university qualification with top skills for founding team members strongly tied to professional university-level qualifications. These include software development (64 per cent), business (61 per cent), marketing (37 per cent), scientific research (13 per cent), engineering (14 per cent) and legal skills (11 per cent).[56]

Case study 1

M is an Australian engineer who graduated 15 years ago with qualifications in avionics engineering. M is the founder and CEO of a start-up company employing 15 people,

[54] Jonathan Russell EA – personal communication re EA analysis of ABS data
[55] Australian Government 2016, Australian Innovation System Report 2016, Department of Industry, Innovation and Science, Office of Chief Scientist, Canberra.
[56] STARTUP SMARTS: UNIVERSITIES AND THE STARTUP ECONOMY, Universities Australia, 2017, https://www.universitiesaustralia.edu.au/australias-universities/Universities-and-the-startup-economy

including other engineers, who work in Australia, USA and UK on data analytics and quantum computing applications. Securing investment capital, client interaction, community engagement, people and project management are part and parcel of M's role.

Case study 2

P is an Australian engineer who graduated 14 years ago with electrical engineering qualifications and worked for a small Australian start-up company spun out from university research. P now works in Australia for another start-up company based in the USA that employs 15 people in different locations around the world on the design and development of a software security platform for mobile and Internet of Things devices. While technical expertise is essential for the work P does, P is also required to interact with prospective customers, clients anywhere in the world, and supervise the Australian group.

While strong technical skills are fundamental to the involvement of engineers in technology intensive start-ups, there is also a requirement for employees in these companies to deploy a broader skill set that demonstrates versatile, agile, flexible, adaptable, persistent and resilient capabilities.

Worthy of note is the declining Australian domestic student interest in engineering careers as evidenced by declining enrolments in professional engineering education programs. In 2017, engineering took only 5.2% of national commencing Bachelor degree students, the lowest proportion on record[57]. The number of new Bachelor graduates in 2017 was 12,000 with 64% (7,741) of these being domestic students. A contributing factor to the declining domestic student engineering commencements may be the recent difficulty experienced by some graduates in finding work. However, for the last decade engineering graduates have consistently had higher full-time employment rates than their peers from other fields[58]. The national graduate survey data shows that that the proportion of graduates from undergraduate degrees in engineering who were in full time work (six months from graduation) declined during 2012 to 2014, but has since recovered. The 2018 survey reported the full-time employment rate as 83.1% for engineering graduates and 72.9% for all fields of education[59]. Further analysis of these employment data is complicated by not having knowledge of whether graduates in non-engineering disciplines are working in non-related disciplines.[60]

A recent analysis of three cycles of census data by Palmer and Campbell [61] also suggests that over the period 2006-2016, the percentage of engineering Bachelor graduates in employment has declined across most age ranges, but the decline has been particularly noticeable for those in the typical new graduate age range. Palmer cites previous analysis of Australian data[62] and older

[57] Australian Engineering Education Facts – Update October 2018, Australian Council of Engineering Deans http://www.aced.edu.au/downloads/ACED%20FACTS%202018.pdf

[58] The Engineering Profession Thirteenth Edition, February 2017 https://www.engineersaustralia.org.au/Government-And-Policy/Statistics

[59] Australian Engineering Education Student, Graduate and Staff Data and Performance Trends March 2019, Australian Council of Engineering Deans http://www.aced.edu.au/downloads/ACED%20Engineering%20Statistics%20March%202019.pdf

[60] ibid

[61] Using census data to better understand engineering occupational outcomes, Palmer and Campbell, Australasian Association of Engineering Education 2018 conference, *Hamilton, New Zealand*

[62] Trevelyan and Tilli, (2010). Labour force outcomes for engineering graduates in Australia. *Australasian Journal of Engineering Education, 16*(2), 101-122.

longitudinal studies from the USA[63] showing significant proportions of professional engineers working outside engineering roles and argues the need for engineering educators in both countries to consider the implications of the increasing proportions of engineering graduates being employed outside traditional engineering roles. No data is available on what skills they are using nor has there been any analysis of the relative value of a professional engineering education. However, worthy of note in this context is the national graduate survey data for 2016, 2017 and 2018 which shows that proportion of engineering (Bachelor level) graduates in both full time and any employment reporting underutilisation of skills is significantly less than that reported for all fields[64]. The 2018 survey cites 21.6 % of engineering graduates in full time employment reporting underutilisation of skills compared with 27.1 % for all undergraduate fields. The corresponding figures for graduates in any employment are 29.7% for engineering and 38.9% for all undergraduate fields[65]. It would be useful to know more about the range of employment outcomes for graduate engineers and the associated deployment of knowledge and skills they have acquired. See Section 10.1, Recommendation 1.

Engineering vacancies in Australia have been much more variable than general vacancies over the last decade[66]. Furthermore, the demand for engineering skills in some sectors has been cyclical and intermittent. Shortages in areas of need have been covered by skilled migration. Analysis of the 2011 census data revealed India as the largest single source of Australia's immigrant engineers. China, and countries in the Middle East and North Africa (MENA) are also sources of skilled engineering migrants.[67] The 2016 census data revealed that more than half (58.5%) of Australia's engineering workforce were born overseas. Engineers Australia summarised "Fast Facts" on engineering employment based on the 2016 census data[68]: this is provided in Appendix 2. A more detailed analysis can be found in the 13th edition (2017) of "The Engineering Profession - A Statistical Overview"[69]. Appendix 2 also provides selected longitudinal data from the EA statistical overview tracking various measures of supply and demand for engineers for the period 2001 to 2016.

A long-standing concern is the lack of diversity in the professional engineering work force and professional engineering education programs in Australia. Considerable attention has been paid to the lack of gender diversity. Less than 14% of the engineering work force is female[70] and less than

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[63] Choy, S. P., & Bradburn, E. M. (2008). *Ten Years after College: Comparing the Employment Experiences of 1992-93 Bachelor's Degree Recipients with Academic and Career-Oriented Majors. Postsecondary Education Descriptive Analysis Report. NCES 2008-155*. Washington DC: National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education.

[64] Australian Engineering Education Student, Graduate and Staff Data and Performance Trends March 2019, Australian Council of Engineering Deans http://www.aced.edu.au/downloads/ACED%20Engineering%20Statistics%20March%202019.pdf

[65] ibid

[66] Engineering Vacancies Report, Engineers Australia, November 2018, https://www.engineersaustralia.org.au/Government-And-Policy/Statistics

[67] Engineering Workforce Review, Australian Workforce and Productivity Agency, https://docs.education.gov.au/system/files/doc/other/engineering-workforce-study-june-2014.pdf

[68] Engineers Australia https://www.engineersaustralia.org.au/sites/default/files/resources/Public%20Affairs/2018/EA%20-%20About%20us%20and%20fact%20sheet_0.pdf

[69] The Engineering Profession Thirteenth Edition, February 2017 https://www.engineersaustralia.org.au/Government-And-Policy/Statistics

[70] Engineers Australia https://www.engineersaustralia.org.au/sites/default/files/resources/Public%20Affairs/2018/EA%20-%20About%20us%20and%20fact%20sheet_0.pdf

17% of domestic students commencing university level study in an engineering program are female[71].

The value of diversity in the workforce, including the positive impacts on business performance is now widely recognised[72,73]. The continuing underrepresentation of women in the Australian engineering workforce therefore presents a significant challenge for the engineering community in this country. Business led programs such as Male Champions of Change[74], the government and academe funded Science in Australia Gender Equity (SAGE)[75] program's adoption of the UK's Athena Swan Charter, the Power of Engineering[76] and various university-led Women in Engineering programs are important initiatives trying to address this imbalance. The Australian Government has recently funded the development of a Decadal Plan for Women in STEM[77] to encourage collaboration between the education, research and industry sectors to increase the participation rates of women in STEM education, and to retain and promote them in STEM careers.

Similarly, the lack of indigenous participation in professional engineering is also recognised as an issue that needs to be addressed.

A number of recommendations were made in 2011 on actions to help address low participation rates of women and indigenes in Australian engineering education by the previous Godfrey and King review[78]. However, participation rates remain at disappointingly low levels.

See Section 10.1 Recommendation 1 and Section 10.2 Recommendation 3.

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[71] Australian Engineering Education Facts – Update October 2018, Australian Council of Engineering Deans http://www.aced.edu.au/downloads/ACED%20FACTS%202018.pdf

[72] Westpac Diversity Dividend Report, Deloitte Access Economics 2017, https://www.westpac.com.au/content/dam/public/wbc/documents/pdf/aw/Inclusion%20and%20Diversity/DeloitteAccessEconomics_WestpacDiversityDividendReport.pdf

[73] Fleming, Nicholas S., 2017, *Engaging people to profit: How to overcome resistance to diversity and prosper through inclusion*, Innergise Pty Ltd, Melbourne

[74] http://malechampionsofchange.com/

[75] https://www.sciencegenderequity.org.au/about-sage/

[76] http://www.powerofengineering.org/

[77] Australian Academy of Science (2019) Women in STEM Decadal Plan, www.science.org.au/womeninSTEMplan

[78] Curriculum specification and support for engineering education: understanding attrition, academic support, revised competencies, pathways and access, Godfrey, King, et. al. 2011, ALTC

3. Anticipating Change and Future needs

The preceding section demonstrates that professional engineers in Australia are currently employed across a wide range of industry and business sectors. The capacity for the profession to accommodate changing demands and expectations has wide reaching implications for future of the profession and its contribution to the national economy and society.

> '*Australia's international competitiveness as a producer of high level and advanced engineering products and skills in the region and globally will be shaped by the ability of Australia's enterprises, educators and engineers to anticipate and effectively meet the engineering skills demands of the future*.'[79]

This section considers issues impacting the future of professional engineering work and reports on consultations anticipating future roles and the knowledge, skills and attributes likely to be demanded of future graduate professional engineers as they enter the work force. It also aims to identify priorities for the education sector and other stakeholders, and issues to be considered in addressing these needs.

3.1 Work is changing – global trends

Dramatic changes, driven largely by the rapid emergence of new technologies and society's changing nature and expectations, are forecast for the future of work. Scientific knowledge, applicable technologies, engineering practice and human needs are evolving and diverging. The 'Fourth Industrial Revolution' (or 'Industry 4.0') and the 'Future of Work' have entered the discourse. According to Klaus Schwab, the

> '*fusion of technologies that is blurring the lines between the physical, digital, and biological spheres*' is predicted to '*disrupt almost every industry in every country and to transform entire systems of production, management and governance*'.[80]

And from the United Kingdom's 2019 report from the Royal Academy of Engineering

> *'The quickening pace of technological advancement and its effect on our society, heighten the need to ensure that all young people develop the broad range of technical, communication and problem-solving skills that will serve them and our society over the coming decades, both as wealth creators and as citizens. This includes nurturing practical skills and creativity, alongside the development of enabling skills such as complex problem solving and critical thinking and professional behaviours such as ethical consideration and environmental awareness, increasingly identified as critical by employers.'* [81]

The 'Engineering Change Lab' initiatives in Canada[82] and the USA[83] are relatively recently developed collaborations that are also focussing on the role of engineering in meeting future challenges, such as massive technological changes, and evolving societal and environmental expectations.

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[79] Engineering Workforce Review, Australian Workforce and Productivity Agency, https://docs.education.gov.au/system/files/doc/other/engineering-workforce-study-june-2014.pdf

[80] https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/

[81] Engineering skills for the future, RAE, 2019 https://www.raeng.org.uk/publications/reports/engineering-skills-for-the-future

[82] https://www.engineeringchangelab.ca/

[83] https://ecl-usa.org/the-problem-3/

3.1.1 Technological driven change

Artificial intelligence and machine learning, augmented reality, advanced automation and robotics including collaborative robots and autonomous vehicles; sensor technologies, the Internet of Things, smart infrastructure, smart medicine, and smart agriculture; big data and data analytics, quantum computing, blockchain technology; advanced manufacturing, 3-D printing, materials science, nanotechnology; biotechnology, smart medical technology; renewable energy and energy storage, are just some of the technologies that are predicted to change our future. Automation, robotics and artificial intelligence enable machines to perform what were previously human tasks. These developments have the capacity to complement and support human endeavours and facilitate the shift in human work towards higher order functions. There will also be a consequential 'hollowing out' of some occupations. The Future of Jobs Report 2018[84] refers to estimates that by 2022 globally as many as

> '*75 million jobs may be displaced by a shift in the division of labour between humans and machines, while 133 million new roles may emerge that are more adapted to the new division of labour between humans, machines and algorithms*'.

Global connectivity via ubiquitous high-speed internet, access to and storage of data, and computing power are increasing at unprecedented rates. The potential of engineered quantum computing hardware and software subsystems that promises a global $37B by 2021[85] is emerging. The growing availability of vast amounts of information means 'Big data', data analytics and artificial intelligence will become increasingly important in supporting human decision making and judgement.

Increasingly sophisticated simulations and virtual reality will be possible - augmented reality is beginning already and will make further in-roads in the future.

Business will increasingly look to recruit people who have expertise and skills that are aligned with these new technologies. A number of reports from industry[86,87] and the education sector[88] are already identifying growing employer requirements in these areas.

> '*As a mining business, you have core skills that you gain from a mining engineer, geologist to traditional professional skills. But we're seeing that those skills need to be combined with some of the new skills of data science, artificial intelligence and how they come together. And the reason is that you want to make good decisions and some of these new technologies can help you and enhance your decision-making.*'
>
> Kellie Parker, Managing Director, Planning Integration and Assets, Rio Tinto Iron Ore[89]

3.1.2 Generic skills are becoming increasingly important

There is also an appreciation of the value of a wider range of generic skills. According to the Australian Institute of Company Directors (AICD) employment is increasingly being concentrated in

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[84] The Future of Jobs Report 2018, http://www3.weforum.org/docs/WEF_Future_of_Jobs_2018.pdf
[85] Australian Financial Review, 12 Mar 2018
[86] WORKFORCE DEVELOPMENT NEEDS: SURVEY REPORT 2018, The Australian Industry Group https://cdn.aigroup.com.au/Reports/2018/Survey_Report_WFDNeeds_Skilling_Sept_2018.pdf
[87] Directors' playbook: The future of work, Australian Institute of Company Directors, October 2018 https://aicd.companydirectors.com.au/-/media/cd2/resources/advocacy/governance-leadership-centre/pdf/glc-directors-playbook-on-the-future-of-work.ashx
[88] CEO perspectives: The future of schooling in Australia. Association of Independent Schools of NSW https://www.aisnsw.edu.au/ceoperspectives/Documents/CEO%20Perspectives_The%20Future%20of%20Schooling%20In%20Australia_Final%20Report.pdf
[89] ibid

service-based tasks that will require a combination of technical and 'soft skills'[90]. The AICD view is that specialists will be working increasingly in cross-functional teams and higher order soft skills such as empathy, professional ethics and emotional judgment are likely to be increasingly valued. This view is reinforced in the 2018 report from The Association of Independent Schools in NSW which analyses interviews held with 15 CEOs, managing directors and leaders to explore the CEO's views on how technology-driven disruption and associated economic and societal changes were affecting their organisations now, anticipated future impacts, and what this might mean for education. Many of the global trends identified by other reports were also cited by the CEOs from a range of organisations in Australia who were interviewed for this report, some of whom say:

> '*Pure technical ability will no longer be sufficient; creative and interpersonal skills will be required even in domains which were once predominantly technical'* [91]

Domain expertise will still be valued, although demands for specific skills are likely to fluctuate and changing skills requirements will lead to greater diversity in the workplace. The rapid pace of change means that some skills will go out of date quickly. Continuing lifelong learning will be essential. Adaptability, flexibility and resilience will be increasingly important. Those working in start-ups and small companies in particular will be:

> '*asked to do things they have no experience in and that things can – and will – change dramatically from day to day'* [92.]

3.1.3 Increasing Globalisation

Globalisation of business and supply chains coupled with global communications technology are internationalising work and work forces. Employers can draw from transnational talent pools and no longer need to rely on the local workforce. An understanding of the world outside one's own national borders will be essential including recognising opportunities and challenges of living in a globalised community and working in international markets. Awareness of global resources and supply chains, as well as the global challenges faced by society at large will be expected[93].

3.1.4 The nature of the workforce and employment is changing

Outsourcing, alliances and networks, and the rise of the 'gig economy' will contribute to a more mobile and flexible work force, increasingly engaged in technology-enabled remote and globalised work. Platforms such as *Airtasker* and *Upwork* will enable business with specific skills requirements to hire specialised workers on a temporary basis. There will be diminishing proportions of long-term permanent work and consequential changes in the physical, digital, and organisational environments in which work happens. The Reserve Bank of Australia reports that part time workers now make up one third of the Australian workforce: however, the percentage of full-time vs part time workers with post school qualifications decreases from 70 – 60% [94].

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[90] Directors' playbook: The future of work, Australian Institute of Company Directors, October 2018 https://aicd.companydirectors.com.au/-/media/cd2/resources/advocacy/governance-leadership-centre/pdf/glc-directors-playbook-on-the-future-of-work.ashx

[91] CEO perspectives, 2018 https://www.aisnsw.edu.au/ceoperspectives/pages/default.aspx

[92] https://www.forbes.com/sites/under30network/2016/07/11/the-first-5-people-youll-hire-for-your-tech-startup/#fe2135818a7d

[93] CEO Perspectives: The future of schooling in Australia. Association of Independent Schools of NSW https://www.aisnsw.edu.au/ceoperspectives/Documents/CEO%20Perspectives_The%20Future%20of%20Schooling%20In%20Australia_Final%20Report.pdf

[94] https://www.rba.gov.au/publications/bulletin/2017/sep/pdf/bu-0917-3-the-rising-share-of-part-time-employment.pdf

3.1.5 Greater societal expectations of trust and social license to operate

Community awareness and expectations around corporate social and environmental responsibility are also growing. Organisations are now expected to operate with social and community investment agendas based around sustainability, community engagement, and environmental protection and stewardship. Gaining and maintaining a social license to operate will be essential if community trust is to be retained and/or regained.[95.]

3.2 Australian perspectives on the changing nature of work and implications for education

Various organisations in Australia and overseas are assessing the likely impact of these changes on the world of work, including professional work such as engineering and the implications for education for this future.

In 2018 the Australian Technology Network (ATN) of Universities in conjunction with PricewaterhouseCooper Consulting Australia engaged with government and industry leaders to consider and report on actions needed to ensure Australia's future workforce has the skills to prosper. According to this study both digital intelligence and enterprise skills will become increasingly important in the future[96].

> *'A growing proportion of jobs will require individuals who can interact with and coordinate people, plan and manage the solving of complex problems, and select and use technological tools. Success in these roles requires what are typically called "Enterprise Skills", "21st Century Skills''," Employability Skills' or "Foundational Skills" – including critical thinking, problem solving, design thinking[9], digital skills, analytics, team working, communication, entrepreneurial skills and creativity.[10]'*
>
> [9]Design thinking is a solutions-focussed, action-oriented methodology used to solve complex problems
> [10]UKCES The Future of Work: Jobs and skills in 2030, 2014

While the Association of Independent Schools of New South Wales 2018 report[97.] explored the future of school-based education many of the report's findings are equally relevant to the higher education sector. CEO's identified the importance of the following points when recruiting employees to their organisations:

1. The ability to function in multidisciplinary teams with diverse perspectives for problem solving. Both emotional and intelligence quotients are important.

   'At Cisco, the skills and capabilities that we're looking for can be quite broad. We find we often develop the skills and capabilities for some of the specific technology requirements that we have but that does need to be laid on a strong foundation, so STEM is absolutely critical to that, but it's not purely STEM. With the earlier-in careers that we're bringing in we look for previously so-called 21st-century skills or enterprise skills. This is a big part of our recruitment phase that we look for: problem-solving, collaboration, creativity, a lot around teamwork and collaboration skills; just working together.' Ken Boal, Vice President Cisco Australia and New Zealand

[95] AICD, https://aicd.companydirectors.com.au/~/media/cd2/resources/advocacy/research/pdf/06457-1-coms-kpmg-ags-trust-survey-report-a4-28pp-v8.ashx
[96] Lifelong skills. Equipping Australians for the future of work. ATN and pwc https://www.atn.edu.au/siteassets/publications/lifelong-skills.pdf
[97] CEO perspectives, 2018 https://www.aisnsw.edu.au/ceoperspectives/pages/default.aspx

2. Engagement as local and global citizens.
3. Enterprise skills (resilience, the ability to deal with failure, curiosity and intrinsic motivation, creativity, problem-solving and global understanding) that will support entrepreneurship and the development of new products and markets that will be important for Australia's future economic prosperity.
4. Domain expertise (strong fundamentals and disciplinary knowledge) that can contribute to real world problem solving in complex contexts.
5. Curiosity and an intrinsic motivation for lifelong learning.

   '*The capacity to learn and master new skills is probably one of the most important attributes that people need going forward. If you think about how fast jobs are changing and how much influence digital for example is having on the workplace, jobs are going to change faster and faster and people are going to need to keep upskilling and reskilling throughout their lives. They're going to need to continually be learning new ways of doing things, new skills, new approaches to solving problems'.* Sara Caplan, Managing Partner PwC Australia

6. Global perspectives i.e. an understanding of the word outside Australia.
7. Real world and authentic learning experiences that contribute to job-readiness.

While domain expertise, and global awareness and citizenship is valued by Australian CEO's in 2018, a stronger emphasis on the value of team work, emotional intelligence, enterprise skills, real world learning experiences and job readiness appears to be emerging in discussions about the future of work and the education system. Poor team work and communication skills are identified in the 2018 AIG Work Force Development Needs Survey Report[98] as a major issue for industry. This report also highlights relative changes in industry priorities when recruiting university graduates and the growing requirements for fit with business culture, enterprise and employability skills (team work and problem solving), and relevant work experience.

3.3 What sectors will employ engineers?

There will continue to be a spectrum of industry sectors and organisations using professional engineers including the sectors traditionally associated with engineering.

Australia's Department of Industry, Innovation and Science has identified the following as areas of competitive strength and strategic priority for Australia's response to Industry 4.0[99]. Engineering has the potential to make significant contributions to these areas in the future.

Manufacturing
Cyber security
Food and agribusiness
Medical technologies and pharmaceuticals
Mining equipment technology and services
Oil, gas and energy resources

Engineering also has an established track record of contributions in these areas. Analysis of the Characteristics of Businesses in Selected Growth Sectors, Australia, 2013-14 indicated that Engineering was identified as the most commonly used skill in undertaking core business in the

[98] WORKFORCE DEVELOPMENT NEEDS: SURVEY REPORT 2018, Australian Industry Group, https://cdn.aigroup.com.au/Reports/2018/Survey_Report_WFDNeeds_Skilling_Sept_2018.pdf
[99] https://www.industry.gov.au/funding-and-incentives/manufacturing/industry-40

growth sectors nominated by the Industry and Innovation Competitiveness Agenda[100]. These include Advanced Manufacturing which cited Engineering at 49% and Trades at 45%. Similarly, for mining equipment, technology and services for which engineering was 48%; and Oil, gas and energy resources at 50%. Engineering was also identified as being required for Medical technologies and pharmaceuticals, and Food and agribusiness, but was not the most frequently cited requirement.[101] Innovation, robotics, defence, space, and smart cities are examples of other possible areas of future growth for engineering and some may emerge as new engineering disciplines or specialisations e.g. security engineering.

Engineering also has the potential to be a key contributor to future developments in the defence and space industries. The creation of 10,000 additional jobs in the space industry is envisioned by Anthony Murfett (Deputy Director, Aust. Space Agency), doubling the current numbers. Areas of operation will include space and ground-based services (3cm GPS to support autonomous vehicles, enhanced earth observation analytics, support to mining and agriculture, and health delivery). Intersections with engineering are strong in adapting current ground-based systems to space-supported platforms[102].

The Department of Jobs and Small Business Industry Projections for five years to May 2023 predicts a 10% growth in employment in Professional, Technical and Scientific Services[103]: according to the 2016 census data more professional engineers were employed in this area than any other. Appendix 3 contains more details. Strong employment growth for professionals is also forecast for the next 5 years including 21% growth in employment of software and applications programmers, 60% of whom will work in professional services [104].

Longer range projections for the future professional engineering workforce are not available.

Engineers Australia is currently conducting a series of round table discussions exploring engineering futures with various industry sectors. Engineers Australia have identified the following areas for further inquiry based on the greatest growth potential, and where the participation of engineers will generate community benefit[105]:

Mining
Transport infrastructure
Manufacturing
Agriculture
Professional services
Public administration

The number of start-up companies and small medium enterprises employing engineers may continue to grow. A record $568 million was raised by Australian start-ups in 2016—73 per cent

100 https://www.pmc.gov.au/sites/default/files/publications/industry_innovation_competitiveness_agenda.pdf
101 http://www.abs.gov.au/ausstats/abs@.nsf/Latestproducts/8170.0Main%20Features12013-14?opendocument&tabname=Summary&prodno=8170.0&issue=2013-14&num=&view=
102 Robin King personal communication re AEC 2018 Australian Engineers and Space conference presentation
103 2018 Industry Employment Projections Report http://lmip.gov.au/default.aspx?LMIP/EmploymentProjections
104 Employment Outlook to May 2023, Department of Jobs and Small Business http://lmip.gov.au/default.aspx?LMIP/EmploymentProjections
105 Engineers Australia, Engineering Futures Committee, Discussion paper, May 2018

more than in the previous year[106]. Similarly, employment of engineers in skilled work that is not classified as engineering may also continue to grow as skills from studying particular degrees are being seen as increasingly transferable: census data from 2011 showed that 40% of university-educated employees were working in industries outside of their field of study[107].

[106] Australian Private Equity and Venture Capital Association (2016) 2016 Yearbook: Australian Private Equity and Venture Capital Activity Report, November 2016. https://www.avcal.com.au/documents/item/1315
[107] Chartered Accountants ANZ, The future of work: how can we adapt to survive and thrive, 2016, https://www2.deloitte.com/au/en/pages/economics/articles/future-inc-series-caanz.html

4. What does this mean for the future of professional engineering work?

Of particular interest to this study is the application and contextualisation of the changes described in the previous section on the changing requirements for professional engineering practice. The following section on the future role of the professional engineer is based largely on the views captured through consultation with thought leaders, and engineering educators.

4.1. What changes will occur in professional engineering work?

4.1.1 There will be a greater diversity of engineering work.

The possibility of there being 'no engineers' in 2035 as the distinction between professionals and others disappears as the result of technological disruption and changing education and social paradigms was raised by one thought leader postulating the emergence of 'blended technical specialists'. A more conservative view emerged from many others although there was strong agreement on there being a much greater diversity in the future spectrum of engineering work. Some believe there will still be a place for routine work. A challenge identified for the engineering team of the future will be to more clearly differentiate the role of professional engineers from the roles of engineering technologists and associates. Several thought leaders were concerned that some professional engineers are currently undertaking engineering technologist activities. The current role description for the experienced engineering technologist states:

> *'The work of Engineering Technologists is most often concerned with applying current and emerging technologies, often in new contexts; or with the application of established principles in the development of new practice…. Within their specialist field, their expertise may be at a high level, and fully equivalent to that of a Professional Engineer. Engineering Technologists may not however, be expected to exercise the same breadth of perspective as Professional Engineers, or carry the same wide-ranging responsibilities for stakeholder interactions, for system integration, and for synthesising overall approaches to complex situations and complex engineering problems.'*[108]

And for the experienced engineering associate

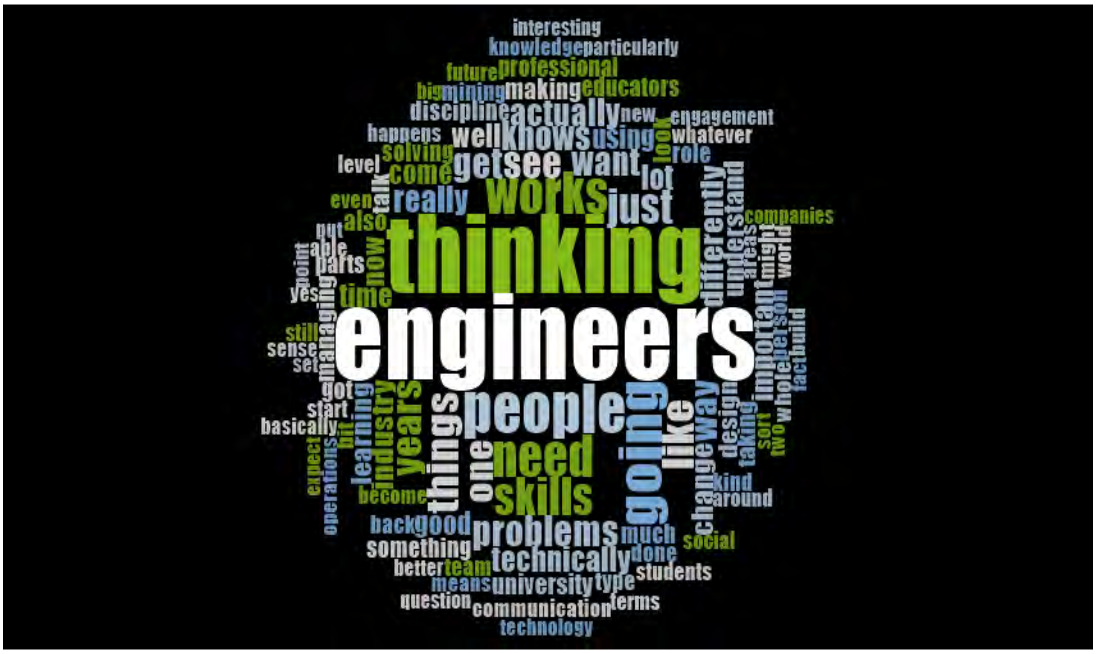
> '*Engineering Associates are often required to be closely familiar with standards and codes of practice, and to become expert in their interpretation and application to a wide variety of situations. Many develop very extensive experience of practical installations and may well be more knowledgeable than Professional Engineers or Engineering Technologists on detailed aspects of plant and equipment that can contribute very greatly to safety, cost or effectiveness in operation.*'[109]

Given the current national interest in technical and further education any future work undertaken by ACED on revising education of professional engineers should also consider the relationship with education of other members of the engineering team.

[108] Engineers Australia. Stage 1 competency standard for engineering technologist https://www.engineersaustralia.org.au/sites/default/files/content-files/2017-02/130607_stage_1_et_2013_approved.pdf

[109] Engineers Australia Stage 1 competency standard for engineering associate https://www.engineersaustralia.org.au/sites/default/files/content-files/2017-02/130607_stage_1_ea_2013_approved.pdf

The work cloud below illustrates the frequency of thought leaders' use of words in the interviews – 'thinking' features prominently.



Other words used by thought leaders to describe future professional engineering work included:

> *Strategists, designers and optimisers of systems; certify; exercising judgement; innovation; creative.*

4.1.2 The future significance of engineering disciplines and specialisation is contested.

Some believe disciplines will still be relevant, graduate recruitment will be based on discipline and there will always be specialisation.

> *'There will certainly be a baseline that somebody who graduates as a professional engineer will need as a discipline…..it's all very well to have all these other skills,…. If you don't know enough technically to contribute, then you're useless'* (TL2)

> *'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.'* (TL8)

Others were less positive.

> *'there's less importance on discipline. We started to recognise the complementarity of certain engineering disciplines which are more closely aligned'* (TL3).

> *'there will be less and less room for those technical discipline space type of people in the future… you will still have specialists in those type of kit (the big 4 engineering disciplines). But they will be more sitting in servicing companies that have that specialised skill'* (TL5)

Greater blending of the "big 4" engineering disciplines and of technical and, operational engineering and the role of auditing of technical business capability was also foreshadowed.

The balance between future demands for specialist versus generalist is impossible to predict. Current discipline-based boundaries are likely to be fuzzier, less rigid, and/or more porous. New specialisations may emerge and demand for some existing specialisations may be more limited or even disappear completely thorough being subsumed into the modus operandi of other more generalist engineering disciplines and systems engineering approaches. Environmental engineering and metallurgical engineering were referenced in this context.

> '*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,'* (TL2)

> *'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'* (TL7)

4.1.3 There are predictions of an increasing focus on systems and integration.

> '*I hope that they end up being strategists, designers, optimisers of systems'* (TL3).

Systems and integration was also a theme pursued in a number of presentations at the 2018 Australian Engineering Conference (AEC) and 2018 CAFEO36 (Conference of the ASEAN Federation of Engineering Organisations) - ASEAN Engineering Deans Summit. Singapore affirmed its need for more of its engineers to have systems and integration skills that will be needed to deal with future transformation/disruption/change[110]. Tim Champion (Arup, UK) claims that future professionals will really have to add value. In engineering, they will focus on outcomes, systems of systems, and be increasingly interconnected. Some of their products will have very long life and implications.[111]

4.1.4 Technical expertise and skills will be expected.

There was strong agreement that technical expertise will be expected although no clear picture emerged on how this could be defined. Society is increasingly being driven by an engineering skill set and engineers are really at the leading edge of technological change in Australian and global society. However, of concern was whether they are becoming more removed from the mainstream of Australian society. Engineers must retain their position as professionals that hold society's 'technical trust at scale'[112] [113].

4.1.5 Some engineering work will continue indefinitely.

Engineers will continue to contribute to the design, development and operation of infrastructure and essential services and systems including utilities, transport, and telecommunications and delivering the ensuing economic and social benefits. A similar situation exists for mining and resources development and operations which will continue despite declining commodity prices and investment, and more difficult ores to find and extract.

> '*The role of a professional engineer as effectively a person who must certify the adequacy of design is still there, that has not changed. But in terms of how that individual arrives at that point, he or she uses that set of digital tools*.'(TL1)

> *'as time progresses there will be more software, there will be more automated machine learning and AI based concepts. We'll see easier methods to manipulate and use big data to make our decision making, but at the same time the purpose of making those decisions will*

[110] Doug Hargreaves personal communication reporting on CAFEO36 – ASEAN Engineering Deans Summit 2018
[111] Robin King personal communication - report on 2018 AEC
[112] https://www.businessinsider.com.au/ranked-australias-20-most-trusted-professions-2015-5
[113] https://thompsonsaustralia.com.au/roy-morgan-image-of-professions-survey-2017/

still be the same as it has always been, which is understand the problem and finding ways to provide a better solution.' (TL8)

The rapid pace of change will also necessitate the professional engineer continually acquiring new knowledge and skills.

4.1.6 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' (TL1).

According to one of the thought leaders interviewed (TL5), economic risk and expediency are the only real impediments to the construction of some fully automated process plants. Maintenance was also raised in this context although what is unknown is the extent to which this will be done remotely with the aid of robotics that can replace human on-site supervision, inspection and interaction.

Improved simulation and virtual reality technologies will enable more creative approaches to engineering design work. The internet of things, big data and data analytics will increasingly support engineering judgement and decision making. Quantum computing heralds the possibility of even further improvements to optimisation and machine learning underpinning data analytics for large complex systems that are beyond today's computational processing capabilities.

Artificial intelligence (AI) will increasingly be inside the 'black-boxes' that engineers will use as designers, managers and end-users. AI and big data will be used by engineers to optimise design and operations in many different arenas, ranging from construction to energy, to software and security. For instance, Tim Champion (Arup, UK) reported that machine learning and data analytics are increasingly important in construction engineering. [114]

AI will have to be developed within robust frameworks of ethics and safety if user and community trust is to be maintained. Engineers will have a role to play.

'*I think we will have an increase in engineers who understand the nuances of privacy. So cyber and information security'* (TL4)

Engineers as both designers and users will be engaged.

'*we are looking for engineers who create new technologies'* (TL4)

'*there is still going to be a requirement for technocrats to manage and oversee'* (TL6)

4.1.7 New materials and advances in additive manufacturing will emerge that will generate new opportunities in a range of sectors. Advanced manufacturing (3D printing) will enable manufacturing of highly complex products on demand. New construction materials will also emerge that will revolutionise the building and construction industries.

[114] Robin King personal communication - report on 2018 AEC

4.1.8 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.' (TL1)*

> *'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.'* (TL6).

4.1.9 Engineering work will be increasingly complex, multidisciplinary and will privilege life cycle and societal considerations.

> '*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*' (TL1).

> *'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' (TL7)*

> *'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'* (TL2).

> '*engineers need to lift their capacity to deal with that complexity and to be able to draw on a whole suite of expertise to support them to make decisions across a border range of responsibilities than traditionally would have been expected.'* (TL2)

4.1.10 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*' (TL1).

> *'I think the technical element is always there, but it is increasing now it gets augmented by the way we engage the owner of the problem in the process, the clients their stakeholders. So that nature of the profession has changed, so you need to communicate work more effectively. You need to be able to co-design solutions sometimes with others, it's not always just you. There's not always a top-down process of I know the right answer and I'm going to give you that, it's more around engagement.' (TL1)*

'we also want them to find problems and solve them. They are not given tasks and then just do them.   we are looking for people who initiate, can see inefficiencies or see better ways of doing things or revolutionise the way stuff is being built or done and how they make a change to that.' (TL4)

4.1.11 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.* (TL2).

The communique issued by the World Federation of Engineering Organizations (WFEO) 2018 International Forum on Engineering Capacity, stated:

'*We should pay attention to humanity, society and nature, and promote sustainable development. We should enhance comprehension of the role of engineering in society and the training of engineering ethics, humanity, nature and entrepreneurship. This will connect the engineering profession closely together with human and environmental wellbeing.'* [115]

Engineers will increasingly be involved in connecting and communicating with others, including communities and society about engineering work and its risks and benefits.

4.1.12 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. The World Federation of Engineering Organizations (WFEO) 2018 International Forum on Engineering Capacity, communique also stated:

'Engineers should not only have deep insights into the technical development trend in some particular fields, but also the ability to cooperate with professionals from different disciplines and different countries to find creative and comprehensive solutions for complex engineering problems' [116].

4.1.13 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 walk across geography, enabled by technology. We can share information very easily these days, work together across the globe and can have*

[115] Consensus of 2018 International Forum on Engineering Capacity, Doug Hargreaves – personal communication

[116] ibid

> *our teams working together on the same project at the same time. So there's that aspect of professional engineers work that has changed*.' (TL1)

The 2018 National President of Engineers Australia, the Honourable Trish White echoed many of these themes in the opening address at the 2018 Australian Engineering Conference (AEC) (*Discover the Future of Australian Engineering*) saying

> '*there should not be a decline in the demand and need for engineers, providing we continue successfully to address disruptions (AI, discipline boundary blurring and commoditisation of engineering services) through our expertise as knowledge-based problem solvers, with integrative perspectives, systems thinking, and (increasingly) creativity in delivering "technology though a human lens*'.[117]

[117] Robin King personal communication – report on 2018 AEC

5. What will it mean to think to like an engineer?

This section considers what it means to think like an engineer and how this can be distinguished from other professionals, such as scientists, mathematicians, technologists, and designers. This draws on work done in the UK as well as the interviews that explored thought leaders' views on the engineering mindset and engineering thinking in Australia.

5.1 Engineering Habits of Mind

A recent study from the Royal Academy of Engineering (RAE) undertaken in conjunction with the Centre for Real-World learning at the University of Winchester identified engineering habits of mind and considered the implications for educators[118]. This work was based on previous investigations of mathematical habits of mind, scientific habits of mind, and intelligent habits of mind more broadly and the implications for learning. Consultations with engineering practitioners and engineering educators in the UK provided the engineering context.

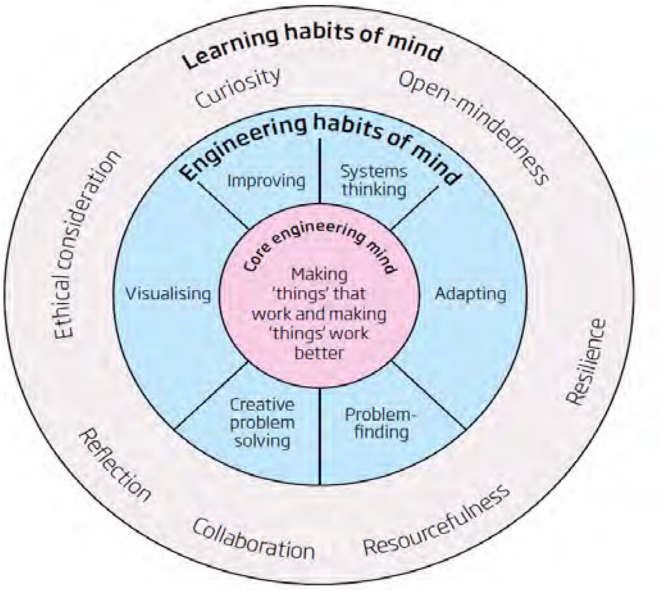
The UK study is based on an agreed premise that engineering of every kind is about "*making 'things' that work and making 'things' that work better*". A strong consensus emerged among the participants on the characteristics of engineering thinking and doing. These are encapsulated in six engineering habits of mind (EHoM): systems thinking, adapting, problem finding, creative problem-solving, visualising, and improving. The report also presents the case for the UK education system to embrace these EHoM as outcomes of engineering education and redesign the education system in order to deliberately develop learners who think and act like engineers. Signature pedagogies associated with engineering education were also discussed. These will be considered further in Section 8.2.

The following figure presents the study's model of the engineering habits of mind (the inner blue ring) and relevant general habits of mind (the outer ring) that were identified by the study as being the most distinctive for engineering.

Most participants in the UK study agreed that all six engineering habits of mind were important at every stage of an engineer's career, but that different stages of an engineering project will use different habits of mind.

[118] Thinking like an engineer. Implications for the education system, Royal Academy of Engineering, May 2014 https://www.raeng.org.uk/publications/reports/thinking-like-an-engineer-implications-full-report

Figure 3: Engineering Habits of Mind [119]



5.2 Australian perspectives on engineering thinking?

Engineers Australia's College of Structural Engineers convened a workshop with approximately 200 engineers at the 2018 Australasian Structural Engineering Conference (AASEC) to explore how engineering education can best prepare and maintain engineers for engineering practice in a rapidly changing world. The participants endorsed the RAE's Engineering Habits of Mind and there was widespread agreement that

> '*tertiary educational institutions must ensure that future engineers are provided with a thorough grounding in 'First Principles Thinking'. The ability to think critically and cut to the chase. To be able to really think about the essence of what is being asked of the engineer. Two fundamental skills of future engineers were emphasised by participants:*
>
> - *The ability to think*
> - *The ability to communicate and collaborate '*[120]

The workshop communique also stated that

> '*it is essential that our tertiary institutions develop a clear understanding of the engineering habits of mind and establish learning outcomes to support these: systems thinking, adapting, problem finding, improving, creative problem solving, and visualising. As engineers move into practice in a changing world, where they will increasingly work alongside artificial intelligence, these fundamental skills will be essential.*'[121]

The thought leaders interviewed as part of this ACED study were asked to describe what it will mean to think like an engineer in 2035 and how this will be different to the thinking of others. Participants' responses to the future of engineering work aligned with a broad interpretation of the view that engineering is about 'making things that work and making things work better.

[119] https://www.raeng.org.uk/publications/other/ehom-poster-royal-academy-of-engineering
[120] ASEC 2018 Engineering Education workshop report, John Wilson personal communication
[121] ibid

'Engineering thinking is about being happy with challenging the status quo, being able to put together fundamentals, what the value is, finding what your objectives are, so what does success look like for this problem, process, service, product, whatever it might be. And what your understanding is, creating that linear logic or what's that framework of things I need to learn and understand to solve this, or get one step closer to solving it. I think that kind of creating this pathway of knowledge, that's what engineering thinking is. And a little bit of innovation along the way is the spark that makes engineering exciting and different from application of standards or something like that.' (TL8)

Many of the EHOM and learning habits from the RAE study were cited in answer to these questions.

Creative problem finding and problem solving;

'*you need to be creative. You need to be a problem finder and have a team around you that can problem solve. So I think that's what it means to be an engineer, it's to be creative,'* (TL3)

'Engineer thinkers are those who can have a general understanding of the right question to ask, and what roughly the right answer should be.' (TL1)

First principles thinking, structured thinking, being analytically rigorous and comfortable talking with uncertainty and numbers were all cited in relation to problem solving.

'*very good at problem-solving and how to think about problems and structuring them'* (TL7)

'going back to the fundamentals and then connecting possibilities in different disciplines, connecting them together to a viable solution….We need engineers who can actually make sense of the answers that are given by machines. And those engineers need to understand the first principles, understand what is the if you like, the order of magnitude of the answer, what it should be'. (TL1)

Big picture thinking and an integrating/systems mindset was strongly endorsed.

'the engineer who can connect the dots, who can think more holistically, who can work across discipline, think about the problem in all its dimensions and use that technical grounding to work with others and develop those higher impact solutions' (TL1)

'they have to be strategists, to be designers and optimisers of systems……The ability to work through scenarios. In the work you're doing, it's to apply that cognitive ability to say in this instance, what does this answer mean? What is the impact? What is the value of this? That is what I think is different' (TL3)

Innovation and optimisation was also cited in a number of responses.

'people who initiate, can see inefficiencies or see better ways of doing things or revolutionise the way stuff is being built or done and how they make a change to that.'(TL4)

'engineers are going to have to be more accountable, more innovative, because to deal with the negatives means that we are going to have to become more creative than we have ever been if we're going to maximise the benefit and minimise the consequences,' (TL2)

Design thinking and imagination was also cited in relation to engineering.

'thinking like a designer is something that is becoming very important for engineering.' (TL1)

we start to form criteria of success, and hence we can find and optimise design which is one design, and we can justify what is a good design is before we get user testing. So we kind of have an impression what something is going to do before we go down. So because of that we get efficiencies in project management, we get cost savings in project management, and we get reliable product, which is a little bit different from design thinking' (TL8)

A number of other terms were also used to describe the characteristics of engineering thinking including **thinking about impact and longevity and understanding risk and asset management**.

There was also considerable agreement with several of the learning habits of mind identified in the UK study including **curiosity, adaptability and resilience**, being characteristic of engineering thinking.

'They (engineers) have a natural curiosity and ability to challenge the status quo' (TL4)

'*Being unfazed by change, being able to see connection no one else can see. Resilience I think is the fashionable word for it, but it's more than that. It's not seeing a problem, it's that's not a problem, we can overcome that, that's not an issue*.' (TL6)

The distinction between science and engineering was also raised.

'most of us think of science and maths and engineering as being together, and they are not, they are completely different ways of thinking… what's directionally correct, well that of course is classic engineering thinking… typically deal with issues where there is not a 100% precise answer.... engineers have to be comfortable with that level of ambiguity, therefore you solve different problems…. it is because you are dealing with systems that you are never going to be precise' (TL7)

6. What changes in knowledge, skills and attributes will be required?

The findings in this section are based primarily on the responses gathered from thought leaders and leaders of engineering education when asked what knowledge, skills and attributes will be expected in the future and how that will be different to now. However, references to other reports and papers are also included.

There was a view that the current set of knowledge, skills and attributes encapsulated in the EA or IEA professional engineering graduate outcomes provide a solid basis for the future. However, the current emphasis on particular elements within these outcomes will need to change, requiring more of a systems approach as the synthesis and interdependence of the outcomes becomes more important in the future. Appendix 4 lists the EA Stage 1 competencies for the professional engineer.

> '*There needs to be a much bigger change in the emphasis and the way we pull them together as a systems model making more visible interdependencies and interconnections'* (TL2)

> '*Knowledge will always be assumed – it's the other bits that have become so interesting'* (TL3)

> *'Engineers will still need to be comfortable with logic, analytical and mathematical thinking, and technical systems'* (TL7)

A shift in emphasis away from knowledge towards intelligence and then wisdom was also suggested.

As reported previously, opinion differed on the extent and nature of the **specialisation baseline** that will be required. Many were of the view that discipline baseline skills will still be needed for an entry level graduate position and that graduates would be expected to have an area of specialisation.

> *'The need for **technical skills** is not going to go away. just the how of it changes*' (TL1)

> *'if you don't know enough technically to contribute then you're useless'*. (TL2)

A different view is that there may be less importance on particular disciplines arising from greater recognition by some employers of complementarity of disciplines. However, an engineering mindset and engineering skills are still required.

> '*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.'* (TL3)

Problem solving and problem definition skills will still be needed. Dealing with ambiguity, uncertainty, being able to make assumptions and use lateral thinking will be required. However, **problem finding skills and holistic problem-solving abilities will become more important.**

Big picture thinking: an understanding of and the ability to work with broader (societal, environmental and cultural) global, and community contexts and values will be essential. **Understanding business and organisational contexts** will also be more important.

> *'having a notion and understanding about how your business operates is important. I think caring about the people who use the technology you build is important. So that's human centred.' (TL4)*

Ethics was also identified specifically in this context

> '*ethics isn't about checkboxes, it's about creative discourse*.' (TL4)

Professional engineers will need to be more comfortable in **working with complexity and unknown unknowns**. Tim Champion (Arup, UK) predicts that '*some (engineers) will be more specialised and (many) will work on harder and more complex problems'*[122]*.*

Entrepreneurship and innovation capabilities will be important. Professional Engineers will be expected to have **skills in *'creating new technologies'*** (TL4) as well as understanding, using, driving development (creating new applications), and managing the new technologies. There will be an expectation that they are

> '*always looking for ways to improve, refine, finesse and never accepting that this is the way it's done'* (TL6)

Digital intelligence skills will be increasingly important as digital technologies (robotics and automation, data analytics, simulation, VR and AI) become pervasive. Skills in understanding and driving these technologies will be more important. Sufficient knowledge and understanding to exercise credible judgement on the level of trust that can be associated with the outputs of 'black-boxes' will be critical. Curation of data has also been identified in this context.

The rise of working in alliances, networks, small groups and cross-functional teams will require new skills and greater emphasis on **people skills** and **emotional intelligence** (EQ). Professor Tim Ibell from the University of Bath is reported as saying this has implications in terms of needing to attract a greater diversity of people into engineering[123].

> *'We do not need engineers with soft skills. We meed emotionally intelligent people with engineering skills. This presents an entirely new paradigm for recruitment of engineering students*

A broad range of responses on skills and attributes that can be seen as manifestations of people skills and EQ that collectively contribute to T-shaped capabilities was received. These included:

Collaborative, multidisciplinary and integrative capabilities that enable an engineering contribution in team work, maximising benefits from other areas of expertise, and recognising that '*engineers are not the definers of everything*' will be more important. Professional engineers will increasingly be expected to embrace and value diversity of thought.

Interaction and engagement skills that can be deployed broadly were also seen as essential for the future. Cultural competencies and communication skills needed to be able to engage with communities and explain engineering solutions in terms of social impacts were also referenced, as was **persuasive communication skills** that can translate technical specialist knowledge into business language and 'broad speak'. Face to face communication skills were also identified as becoming more important.

> *'communication is a technical competence…. You're not going to perform well in your technical competencies if you can't communicate. And you're not going to perform well with your efficiencies of your technical competencies if you don't work for the team.'* (TL8)

Other attributes that have been identified by thought leaders include:

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[122] Robin King personal communication – report on 2018 AEC

[123] What skills do the engineers of the future need?, 2018 https://www.raconteur.net/business-innovation/engineering-skills

Adaptability, flexibility, and comfort with change, including the agility to translate disruption into opportunity, multitask, and apply skills to different sectors, including non-engineering domains. This also includes

> '*being nimble and having the self-confidence to take whatever you've been taught and to be able to apply them at different times and differently throughout your life for your own purposes and also in response to the way in which the employment market might change'* (TL6)
>
> i.e. *'a quality of being unfazed, being unfazed by change'* (TL6).

Other attributes included, embracing lifelong learning, being inquisitive, open to learning; open to improving; always looking for ways to improve, refine, and finesse and never accepting that this is the way it's done.

The thought leader views on expectations around future knowledge, skills and attributes expected of professional engineers can be grouped roughly into continuing and changing needs as shown in the following table. An ongoing challenge for engineering educators and employers of graduates is to acknowledge that these qualities evolve and mature with time and experience in practice and that there will be further gains in these outcomes as a new graduate develops into an experienced practitioner.

Table 1: Future Knowledge, Skills and Attributes for professional engineers

Continuing requirements	**Future needs will require a greater emphasis on T shaped capabilities such as**
Technical expertise	Human focussed big picture systems thinking
Problem definition	Problem finding
Problem solving	Creativity and innovation
	Digital intelligence
	Collaboration and communication
	Adaptability and resilience

7. Priorities for future engineering education programs

This section reports on themes emerging from the responses from the thought leaders interviewed when asked for their views on future educational priorities for the years of formal education, and the Engineering Deans' and AAEE conference delegates' views on changes required including in curriculum and pedagogy to address future needs.

7.1 Educational culture, organisational structures and funding models

Both a better understanding and changing the culture of engineering education including the attitudes of staff and the attitudes of the academic organisation is needed. Several observations were made about the engineering profession privileging conversations with and about industry over conversations with and about society, leading some respondents to suggest there is an opportunity to redress the imbalance, put people back at the heart of engineering and take greater advantage of students' desire to make a contribution to society.

> *'it is very much also about understanding the culture of the teaching environment and the academics and technical staff and how they all role model issues as well. So it's not just about curriculum, it's about the whole culture that we structure within engineering education'* (TL2)

The need for breaking down silos was a consistent message. Funding models that encourage a breakdown of the silos in university departments, schools and faculties to facilitate more flexible boundaries, greater teaching/sharing of students across these boundaries leading to greater multidisciplinary exposure and awareness across not just engineering disciplines, but also more broadly into areas such as business, law, science, and IT were identified by many as being fundamental to addressing future expectations.

> *'if it's (engineering education) going to continue to be relevant in the future it perhaps needs to look at itself and take on board that the way that it deals with multi-disciplinarity, that it role models the type of attitudinal engagement that you need with the broader societal and environmental issues without the engineers having solved it all themselves'* (TL2)

Concerns were also raised about the ability of current structures to pursue a more practice based (externally focussed) approach that involves working beyond organisational borders to better develop the ability to practise. Universities working together to deliver capstone experiences that include international dimensions, stronger connections with industry such as a full set of design courses which depend on industry, spending more time in industry than at university, and being able to explain engineering solutions in terms of social impacts were seen as requiring organisational/structural change.

Organisational processes were also mentioned as needing to be more nimble so as to encourage and enable agile responses to change.

7.2 Engineering educators

The nature of the engineering educator workforce has emerged as another area in which change will be needed. There were strong views that new types of academics will be needed, that more academics/educators who are in tune with and can adapt to changes occurring in professional practice are needed, and that 'generational change' in the educator workforce is due.

Greater diversity in the engineering education workforce including more educators who have industry experience and have 'been in the frying pan' rather than moving directly from undergraduate and postgraduate research studies into an engineering educator role was seen as increasingly important. Industry exposure for both staff and students was seen by many as a high priority.

Male, King and Hargreaves[124] reported in 2016 a related finding from a study undertaken as part of the ACED Industry Engagement project.

> *'Interviewees and forum participants expressed perceptions that academics were not sufficiently aware of the needs of industry or society, as demonstrated by this quote.*
>
> *'I think it requires the universities themselves to recognise who the stakeholders are and what their stake is in the issue. It's not – it shouldn't be – the driver shouldn't be the curriculum and the funding and – that's here for a purpose which should be based on industry need and... in fact I think it's beyond that too. It becomes the social and physical climate as well because that's going to drive what becomes important in the near future, you know, we've got a megatrend is really… much more connected to society and that's bringing with it opportunities and real risks and that should be debated and discussed. (National head of human resources for a consulting engineering firm)''*

Several thought leaders also cited the need for educators who can adopt a better integrated and a more systems-oriented approach to education. Systems was used broadly in this context as meaning the linking and contextualisation of multiple educational outcomes. A number of thought leaders also cited the so called 'soft skills' or 'interaction and engagement' skills as being essential and part of an 'engineer's technical tool kit': consequently there is a need for engineering educators who can own and engage with students in developing this broader more integrated skill set.

> '*simplistically people break them into hard skills and soft skills. I think one of the opportunities is not to see them as two different things. It's not a soft skill of its own, a soft skill that is relevant in the context of the hard skills. For example, when you say communication, it's not the general communication training, it's how you communicate engineering. I think that needs a new breed of educators who are actually great engineering communicators. Yes they understand the power of storytelling, but it's about the content of the story, which is engineering and its impact and how you work together…. ownership has to stay with the people that teach hard skills'* (TL1).
>
> *'I don't think we have thought very carefully about going back to that systems issue. I don't think we've thought about how they all work together to come up with a suite of skills that the professional engineer can use effectively'* (TL2).

In a similar vein, engineering educators who can work in collaborative teaching teams e.g. with lawyers, archaeologists, and engineers from different disciplines to engage with broader societal and environmental considerations are needed.

Other desirable characteristics of the future engineering educator workforce were suggested as including: more educators who are inspiring role models; educators who can engage with students in innovation; and educators who are more comfortable with uncertainty.

[124] Male, Sally, King, Robin, & Hargreaves, Douglas (2016) Drivers and barriers to industry engaging in engineering education. In 12th International CDIO Conference, 12-16 June 2016, Turku, Finland. https://eprints.qut.edu.au/96563/3/96563.pdf

The ASEC2018 Engineering Education workshop report[125] also identifies as essential, educators who have the ability to inspire future engineers and endorses:

> *'the value of our teachers and mentors in the tertiary educational institutions to inspire our future engineers about the purpose of engineering as it contributes to improving our world for the benefit of the wider community. A number of contributors spoke about the lasting impact on their future careers from educators who had the ability to inspire them and to relate to them on a personal level. This critical role of the educator is often overlooked'.*

7.3 Program outcomes, structures and pathways

There are consistent messages about the Australian engineering education system needing to provide a greater diversity of educational outcomes to meet future needs.

Demands for creative versus routine, specialist versus generalist and more holistic/systems capabilities and outcomes will need to be addressed.

Consideration will also need to be given to programs that can address entrepreneurship and innovation: this can be approached from various perspectives ranging from being engaged in sustainable futures to the founding of another 'Apple'.

The engineering education system needs to consider how to prepare the range of graduates for the growing and diverging areas of demand. There is a strong case for increasing diversification in the range and scope of professional engineering degrees and 'entry to practice' pathways.

Increasing diversity in the student intake will also need to accompany any broadening into a more diverse set of educational programs and pathways. Diversity in this context is defined broadly and includes gender, indigenous, cultural and cognitive diversity.

The limitations of the dominant conventional 4 year bachelor degree versus other programs including those with significant components of work integrated learning, the balance and split between undergraduate and postgraduate education (including the 'Melbourne model'), and the desirability of new and different education models including polytechnic and graduate school type programs were issues raised in relation to providing the greater diversity of educational outcomes that will be needed in the future.

Suggestions that an engineering education could be envisaged in the form of a 'new liberal arts degree' and recognised for its problem solving and design focus, mathematics and science foundations, and the development of judgment and capacity for lifelong learning have been heard in various forums.[126]

Risk acceptance by universities and professional accrediting bodies such as Engineers Australia will also be necessary in order to pursue accelerated evolution and innovation 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'*. (TL2)

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[125] ASEC 2018 Engineering Education workshop report, John Wilson personal communication

[126] Robin King notes on AEC 2018 ***Engineers as part of the great leap forward***, a panel including ACED members Prof Eleanor Huntingdon (ANU), Prof Elizabeth Croft (Monash) and Prof Euan Lindsay (CSU) and the AAEE conference delegates workshop responses.

7.4 Curriculum and pedagogy

Changing curriculum and pedagogy was also cited by most respondents with a long list of recommendations being provided. Key themes in this area are as follows.

What will not change is the fundamental purpose of a formal engineering education being about learning how to learn, nurturing the deployment of engineering habits of mind, and acquiring a technical tool kit and competence in using this.

> '*you go to engineering school to learn tools to fill your toolbox. And the same time, reshaping your mind …..the skill sets of an engineer is not about what you learn but you learn how to learn.'* (TL8)

Preparation for lifelong learning is a consistent theme from a variety of sources. Learning how to learn and recognising that rapidly changing, business, economic and social environments means that graduates will need to learn and relearn throughout their careers. Curricula will need to ensure that students learn how to learn and understand the value of continuing lifelong learning.

Curriculum will need to adapt to digital technology changes and address the impact of these changes on engineering work.

> *'- how do you best augment or collaborate with it (computers/machines), it's those aspects of technical sense making effectively is I think needs to become more of a focus and less of teaching people technical processes….. train or educate engineers to interpret the results of computers or machines. And that I think is a core skill'* (TL1)

> *'Nowhere in this program are you dealing with automation and what that actually means. How does this change the way work is done?'* (TL3)

The development of technical expertise is seen as essential and will continue to be expected, but there is a range of views on what this means. Diverse views on the future expectations around disciplines and specialisations required and how this affects curriculum will need to be further explored as both specialists and more broadly-based integrators will be required. In 'Rethinking Engineering Education'[127] this is expressed as the '*tension between two key objectives within contemporary engineering education: the need to educate students as specialists in a range of technologies—each with increasing levels of knowledge required for professional mastery—while at the same time teaching students to develop as generalists in a range of personal, interpersonal, and product, process, and system building skills*'.

> *'what you would want the 1st degree to be made of because you don't spend as much time in the routine manual processes you have really impactful technical content, but also get people to bring an open mind, to think about the context of their discipline in a broader sense…..the breadth is to be able to have a general understanding of what the other participants are in the process of delivering a solution. It is not just your discipline lens, yes it only solves part of the problem, whereas the unit is a holistic aspect of a problem to be solved.'* (TL1)

> *'Common first year engineering will soon become two-years common engineering. It will soon become three-years common engineering'* (TL3).

[127] Rethinking Engineering Education The CDIO approach, Crawley et al., 2014,

'I think there will be a base where everyone is going to have to have a level of electrical and computer science that will just be absolutely foundational.' (TL7)

The role of postgraduate education was also raised.

'we probably need a bit more postgraduate specialisations in my field. So for example, engineers can be hired as design engineers, they can be regulatory people, they can be quality people, or manufacturing people…. They seem to me to be post-graduate skills.' (TL8)

Strengthening the 'integrative nature' of the curriculum will be required. The breaking down of silos will be central to delivering on this outcome.

'you don't need to learn integrated thinking over 20 years. You can learn it at university so that the early phase curriculum should include asset management, people management, risk management, safety management type of subjects for engineering skills' (TL5)

'Appreciating different perspectives - you have to solve for the team all the time, you don't just solve for each individual' (TL7).

Integrative curriculum was also referred to as including teaching different subjects in an integrated way and ensuring better visibility of connections, better linking and contextualisation of 'soft skills' as quoted in the section on engineering educators, a greater focus on skills that need to be applied, less about specific knowledge about particular areas, and scaffolding that is essential to develop these skills.

A greater focus on the development of personal attributes such as EQ, resilience, creativity and interaction and engagement skills is also envisaged. Adrian Turner CEO Data61, CSIRO when asked 'Which skills and character traits do you look for as an employer?' is reported as saying

'First of all I look for EQ (emotional quotient), I think that because the context – the business context and market context – is changing so quickly; the ability for an individual to go and change the world by themselves is a lot harder than in the past, it requires teaming. And so, communication skills and the ability to work with others is fundamentally important, as is the ability to problem solve.' [128]

More exposure to systems/life cycle assessment and thinking is needed as ethical considerations and societal and environmental impacts will need to be better understood.

'I want 25% of 3rd and 4th (year) dedicated to those social things…. social impact needs to be front and centre. Perhaps going to the foundational side of the degree, say this is why as engineers these are our responsibilities. And you need to think about everything you do through these lenses' (TL3)

A greater emphasis on experimentation and opportunities to practise and fail was also suggested.

'what I think should be more emphasised on educational practice is the notion of experimentation. So you do actually iterate on a potential solution for a problem, as opposed to assuming there is a perfect predetermined solution to a predetermined problem - if you do

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[128] CEO Perspectives: The future of schooling in Australia. Association of Independent Schools of NSW https://www.aisnsw.edu.au/ceoperspectives/Documents/CEO%20Perspectives_The%20Future%20of%20Schooling%20In%20Australia_Final%20Report.pdf

> *experimentation that means you will have failures and things that don't work…. the speed and the cost is lower to do it digitally'* (TL1)

Similarly, greater use of open–ended problems rather than working of closed solution problems will be required.

> *'my biggest suggestion, if I was rewriting the syllabus would probably be around more of a problem-based approach.*' (TL8)

The CEO's perspectives report[129] also identified this in relation to assessment practices in education.

> 'Competencies that brought knowledge, skills and capabilities together in a real-world context. '*The current focus on external assessment measures that privilege memory and rote learning at the expense of competency development was identified as a significant problem for educators to attend to'*.

More collaborative pedagogies and project management of solutions that are developed from teams of different disciplines should be associated with finding and solving of open-ended problems. Problem Based Learning (PBL) and Project Centred Curriculum are well established models that have potential to meet these needs and should be further explored.

> *'you have a set of engineering disciplines, but they need to work with people in social science or people in other disciplines or creative people like architects, and developing that understanding and teaching people that there are different design processes'* (TL1)

Stronger connections with industry are needed. Teaching collaborations should also include more collaborations with industry as staged exposure to industry is seen as important.

> '*you actually need to observe work to be able to improve it. – should be a bit more blended learning'* (TL5).

Spending more time in industry than on campus was also suggested. The CEO's perspectives report[130] also cited 'Post school opportunities that facilitate the '*transition to work and life including the creation of portfolios, which better documented their capacities and skills*'.

7.5 Educational environments

Learning outside traditional campus environments will become more prevalent and is likely to take place in a greater range of physical and virtual environments than ever before. Possibilities include: greater use of Work Integrated Learning (WIL); and further embedding of industry precincts, incubators and accelerators into education and bringing industry into the campus. Educational technologies are enabling greater use of blended and on-line learning that makes more extensive use of collaborative learning, virtual reality and simulation.

7.6 Findings from other similar reviews

Many of these findings are closely aligned with the outcomes of similar projects undertaken in other countries and previous work in Australia.

[129] ibid

[130] CEO Perspectives: The future of schooling in Australia. Association of Independent Schools of NSW https://www.aisnsw.edu.au/ceoperspectives/Documents/CEO%20Perspectives_The%20Future%20of%20Schooling%20In%20Australia_Final%20Report.pdf

In the USA the American Society of Engineering Education (ASEE) is undertaking a multistage project with support from the National Science Foundation on Transforming Undergraduate Engineering Education (TUEE). In 2013, industry representatives investigated the knowledge, skills, and abilities (KSA) needed now and in the future. *'Participants identified core competencies that remain important for engineering performance, but added an array of skills and professional qualities needed in a T-shaped engineering graduate—one who brings broad knowledge across domains, deep expertise within a single domain, and the ability to collaborate with others in a diverse workforce.' Participants found current training to be inadequate to meet present industry needs and badly out of sync with future requirements.'*[131]

The 36 KSAs are presented in Appendix 5.

Producing T shaped professional outcomes i.e. '*an engineer who is both technically accomplished and able to succeed in a team-driven, culturally and ethnically diverse, and globally oriented workforce*'[132], along with the recommendations from the NAE Engineer of 2020[133] project became the major framework guiding phase II of the TUEE study during which student engineers were invited to express their view on strengths and weaknesses of curricula and pedagogies with reference to the 36 Key Skill Areas (KSAs) established in Phase 1.

The Phase II study reported that educational institutions in North America were paying insufficient attention to KSAs needed to produce T shaped outcomes i.e. engineering schools traditionally focussed on instilling deep disciplinary or domain knowledge and application (the vertical stem of the T), with insufficient attention being given to the horizontal bar skills such as cross disciplinary collaboration and team work. More appropriate pedagogies (including project-based learning and experiential learning), greater diversity in the engineering educator workforce (including industry experience) and better training of educators were identified as major areas needing improvement.

Engineering educator training and support to optimise use of sound practice-focussed pedagogies and greater industry engagement in engineering education thereby strengthening the authenticity of engineering education were identified in Australia's 2008 King review of engineering education as needing improvement[134]. King also found that '*progressively fewer engineering academic staff have recent industry experience (other than in research laboratories) that they can use in the classroom*'. A survey of engineering academics undertaken by Cameron, Reidsema and Hadgraft in 2011[135] found that there were concerns with the extent and currency of industry experience and that '*overall lack of experience in deep practice knowledge casts doubt on our ability to define and operate curricula more strongly in areas of authentic engineering problem solving, engineering application and practice, with themes of design, the engineering life-cycle, complex systems, and multi-disciplinarity.*' Of prime importance was the '*strengthening of academics with relevant and timely industry*

[131] American Society for Engineering Education. (2017). Transforming Undergraduate Education in Engineering Phase II: Insights from Tomorrow's Engineers. Workshop Report. Washington, DC. https://www.asee.org/documents/publications/reports/2017TUEEPhase2.pdf

[132] American Society for Engineering Education. (2018). Transforming Undergraduate Education in Engineering Phase IV: Views of Faculty and Professional Societies. Workshop Report. Washington, DC. https://www.asee.org/documents/publications/reports/2018TUEEPhase4.pdf

[133] Educating the Engineer of 2020, National Academy of Engineering, 2005, p51-58, The National Academies Press

[134] Engineers for the Future addressing the supply and quality of Australian engineering graduates for the 21st century, King, ACED 2008

[135] Australian engineering academe: a snapshot of demographics and attitudes, by Cameron, Reidsema and Hadgraft, 52 Proceedings of the 2011 AAEE Conference, Fremantle, Western Australia

experience; informing and promoting the nexus of theory and practice coupled with real-world contexts for problems and projects.'

The European Society for Engineering Education (SEFI) position paper[136] on developing graduate engineering skills also identifies the engineering educator and their relationship with industry as needing greater attention in European engineering education. The SEFI paper also echoes many of the themes cited by thought leaders in Australia about changing expectations around graduate outcomes related to: adaptability and broadening, greater diversity, connections with industry, and lifelong learning.

7.6.1 Reviewing 'The Global state of the art in engineering education' report

The engineering education sector is entering a period of rapid change. The global state of the art in engineering education report[137] published in 2018 canvassed views of 178 global thought leaders in engineering education on current and emerging best practice. This section outlines key issues and themes identified by the review. Distinctive features of education programs considered by thought leaders to be leading the development of best practice included '*work-based learning, multidisciplinary programs, and a dual emphasis on engineering design and student reflection*'. Case studies suggest that these programs have benefited from '*strong and visionary academic leadership, a faculty culture of educational innovation and new tools that support educational exploration and student assessment*.'

Features of current best practice programs were identified as '*user-centred design, technology-driven entrepreneurship, active project-based learning and a focus on the rigor in the engineering 'fundamentals''*.

However, a striking characteristic of many of the universities identified as 'current leaders' is that the cited good practices in engineering education are often isolated, confined to 'pockets', with limited connectivity to the rest of the curriculum. Much of the benefit of these experiences often remains unexploited because they are unconnected with other curricular experiences; in consequence, students are not encouraged to reflect upon and apply what they have learned in other areas of their degree program.

In contrast to the 'current leaders', many institutions identified as the 'emerging leaders' are distinguished by their integrated and unified educational approach. Experiences, such as work based learning and societally-relevant design projects, are central to the program, and provide a platform for students to contextualize, reflect upon and apply the knowledge and skills they have gained elsewhere in the curriculum. However, many of these educational exemplars – such as at Olin College of Engineering and Iron Range Engineering in the USA cater to relatively small cohort sizes.

The key innovations that are likely to define the next chapter for engineering education are the mechanisms by which such features can be integrated at scale and delivered to large student cohorts under constrained budgets. University College London (UCL) and Singapore University of Technology and Design (SUTD) are cited as exemplars.

Barriers to change were also investigated and identified as '*aligning government and higher education goals, the challenge of delivering active learning to large student cohorts, the siloed*

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[136] Developing graduate engineering skills, SEFI, 2017, http://sefibenvwh.cluster023.hosting.ovh.net/wp-content/uploads/2017/07/POsition-Paper-on-Engineering-Skills.pdf

[137] The global state of the art in engineering education, Ruth Graham http://neet.mit.edu/wp-content/uploads/2018/03/MIT_NEET_GlobalStateEngineeringEducation2018.pdf

monodisciplinary structure of many engineering schools, and faculty appointment and promotions systems that are not recognised as rewarding teaching achievement'.

Concerns about the alignment between governments and universities in their priorities and vision for engineering education include:

a) lack of consensus about the purpose of engineering undergraduate education and tensions arising from differences in preparation of researchers versus practitioners

b) restrictions imposed by national accreditation requirements

c) unpredictability of government higher education funding and policy, and restrictions on funding to support educational innovation and support networks.

In terms of the challenges around delivering at scale:

a) The majority of thought leaders anticipated that "team-based, hands-on student learning that responds to the needs of society and industry" would underpin the world's leading engineering programs in the decades to come. However, concerns were repeatedly expressed about the capacity of large, publicly-funded institutions to deliver such educational programs to large student cohorts.

b) many of the educational features common to the 'current leaders' and 'emerging leaders' in engineering education, including entrepreneurial or authentic industry experiences, are only available to relatively small student cohorts

c) increasing student numbers would inevitably bring a greater diversity in student demographics and background and a more diverse student body was not well served by current engineering curricula.

The siloed nature of many engineering schools and universities was seen as inhibiting collaboration and cross-disciplinary learning:

a) multidisciplinary learning and increased student choice were predicted to be key features of the best engineering programs over the coming decades.

b) Many of the high-profile engineering and technology universities established in recent years have been created without traditional engineering disciplinary boundaries. Other highly-rated institutions …."soften the [existing] boundaries" between engineering disciplines and create more opportunities for cross-disciplinary collaboration and learning.

'Faculty appointment, promotion and tenure systems that reinforce an academic culture that does not appropriately prioritize and reward teaching excellence' emerged from interviewee feedback on "the reluctance of faculty to change because they are in an environment where education is not rewarded by their university." In particular, the criteria by which faculty are appointed and promoted were repeatedly cited as a major inhibitor to educational excellence and capacity to reform.

Future global trends are predicted to be: '*a geographical shift in engineering education leadership away from North America and Europe to Asia, South America and Australasia; a move towards more socially relevant and outward-facing engineering curricula… including distinctive student-centred curricular experiences; and the delivery of distinctive student-centred experiences at scale.*'

The geographical shift in engineering education leadership away from North America and Europe to Asia, South America and Australasia will be driven by strategic investment in undergraduate engineering programs to drive national economic growth. The review cited significant investment in China and South Korea and developments in Singapore along with increased competition and diversification in engineering education.

The move towards a more human focus in engineering education is seen as requiring more socially distinctive curricular experiences such as

a) student choice and flexibility including a move away from students being seen as scientists and future PhD students
b) multidisciplinary learning both within and beyond engineering
c) greater focus on the role, responsibilities and ethics of engineers in society and solving human challenges and the problems facing society
d) global outlook and experiences increasingly focused on the development of "skills to be effective in a global environment," and providing students with a range of opportunities to work across nationalities and cultures
e) breadth of student experience outside the traditional engineering disciplines and outside the classroom e.g. work based learning.

The educational features and approaches listed above are not radically new: societally-oriented, multidisciplinary curricula that expose students to a breath of experiences, for example, are established features of many engineering programs worldwide.

This review asserts that the key challenge for the future will be the ability of engineering programs to 'pull together' and integrate best practice experiences at scale. Key innovations that will define the next chapter of global engineering education are unlikely to be new teaching techniques or curricular components, but rather how programs are managed, structured and delivered in practice.

7.7 Other international developments in engineering education

In Singapore several new engineering programs have been implemented around frameworks that are more human/societally and design focused: The Nanyang Technological University's Renaissance Engineering program is a broad-based, inter-disciplinary engineering dual-degree programme which integrates Engineering, Science, Business, Technology Management and Humanities, and leads to the award of a Bachelor of Engineering Science coupled with a Master of Science in Technology Management. Singapore University of Technology and Design (SUTD) is not structured around traditional engineering silos and offers multidisciplinary and design focussed engineering programs such Engineering Systems and Design. Mr Teo Chee Hean, the Deputy Prime Minster and Coordinating Minister for National Security Singapore delivered the keynote address at the 2018 Conference of the ASEAN Federation of Engineering Organisations stating, ASEAN need more engineers and their vision for the future of engineering is framed around: Connectivity; Innovation and Industry 4.0; the integration of engineering and finance; and sustainability and resilience. Climate change and future proofing of infrastructure are key considerations. In terms of engineering education, the following are seen as being required: a focus on lifelong learning and educating for an ever-changing world, creativity and a more integrated system[138].

Prof Chong Tow Chong, President Singapore University of Technology and Design (SUTD) which is one of the case studies presented in the Global state of the art in engineering education report confirmed that critical areas of need are (1) to break down silos (2) skills and attitudes beyond book

[138] Doug Hargreaves report on 2018 CAFEO36, personal communication

knowledge (3) flexibility in choice and diversification (4) pedagogical innovation and lifelong learning and (5) partnerships with industry.

In the UK the NMiTE initiative[139] that is currently being developed aims to introduce a new model for engineering education in Britain using different approaches to student recruitment, and student learning where '*student engineers will work collaboratively in small groups, on real-world engineering problems set by real-world organisations, mentored by real-world engineers'* via a curriculum that *'will place learning-by-doing over lectures, and portfolio assessment over exams'*, and facilitate the graduate transition into professional practice.

CDIO™ is an engineering educational framework that grew out of a collaboration initially between Scandinavian universities and MIT on designing engineering curricula and assessment. The framework is based on Conceiving — Designing — Implementing — Operating (CDIO) of real-world systems and products[140] and is now the basis of a global network of educational collaboration and communities of practice. Several Australian universities are members of the CDIO initiative.

7.8 Changes in the tertiary education landscape

The technological developments and societal change that is reshaping the world is also driving change in higher education.

Higher education has been massified with greater numbers and diversity of people than ever now engaged in tertiary education and continuing lifelong learning, both as providers and consumers. The challenges accruing from the scale and diversity of the global higher education landscape will lead to increased choice for consumers and competition for providers for whom scale and diversity will be challenges.

Information is readily available on the internet and it now possible to obtain a university degree through on-line study e.g. The University of Phoenix[141]. Udacity is now offering on-line nanodegrees that are project and skills-based educational credential programs[142]. Robotics software engineering, artificial intelligence, and machine learning courses are available for study with Udacity. In Australia the Engineering Institute of Technology[143] is a private provider that is now offering an accredited Master of Engineering program that is delivered on-line via interactive virtual classrooms and webinars. The University of Southern Queensland and Central Queensland University have also offered accredited professional engineering programs in distance/external mode for many years. Almost all technical engineering knowledge is now available on-line and can be accessed by students as and when they need it.

The ready availability of information and resources on-line has resulted in increased use by all universities of on-line learning, blended learning and the development of both Small Private On-line Courses (SPOCs) and Massive Open Online Courses (MOOCs). SPOCs are usually a version of a MOOC for local use with on-campus students. Universities from around the world are developing on-line resources and participating in global MOOC platforms such as Coursera, edX, Futurelearn and Udacity. Various Australian universities are contributing to these as well as to the Open2Study MOOC platform developed by Open Universities Australia (OUA).

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139 https://nmite.org.uk/about/
140 http://www.cdio.org/
141 https://www.phoenix.edu/
142 https://www.udacity.com/
143 https://www.eit.edu.au/cms/

The growth of on-line education resources has profound implications for the value-add of a campus-based education. Campus-based learning is being transitioned away from a traditional focus on transmission of information lectures towards more active, student-centred learning experiences. Delivery of more active, student-centred learning at scale is a challenge that will need to be addressed in future on-campus education. Both the on-line and campus-based learning environments are changing rapidly and to some extent, merging.

Micro-credentials or digital badges are acquired via completion of short on-line courses that are focussed on small, discrete elements of learning. Universities, employers and accrediting bodies are currently considering how this form of education might be recognised and accommodated in various educational pathways and what this means for assessment and certification that has previously been validated via conventional degree pathways.

Employability has also entered the discourse of business, government and education including higher education. Embedding employability thinking as a developmental process that is part of higher education is the goal of 'The Developing EmployABILITY Initiative'[144]. This initiative received Australian government funding and involves collaboration across 30 higher education institutions and over 700 scholars internationally.

> *'EmployABILITY thinking engages students as partners in their development. As a cognitive approach, employability thinking aligns employability with both the purpose of higher education and the future of work……*
>
> *Every student should engage in employability thinking. This can be achieved through careful scaffolding of work-integrated-learning (WIL), through reflective and assessment tasks that include a future-oriented dimension, and through pedagogical approaches that develop students' metacognition. '*[145]

Given the growing interest in developing a broader skill set, including enterprise skills and including greater exposure to practice in education, the role of employability and employability thinking in all future education programs also needs careful consideration.

[144] https://developingemployability.edu.au/about/
[145] ibid

8. The current engineering education landscape in Australia

8.1 An overview of engineering education in Australia

In Australia, the education of an entry level professional engineer generally involves 4 or more years of post-secondary level education. Australia currently has 35 Universities and several private providers offering professional engineering degrees that are accredited by Engineers Australia for entry to practice[146]. A number of these providers also operate offshore campuses offering engineering degrees. Since 1980, the standard accredited professional engineering qualification has been the 4-year Bachelor degree, and from 2015 has been an Australian Qualifications Framework (AQF) level 8, Bachelor (Honours) degree. This remains the principal qualification for domestic students. However, there are now increasing numbers of entry to practice Master degrees available: these are particularly attractive to international students.

Australia's current engineering education system has served Australia well. Education is a central pillar of Australia's economy and the largest services export. In 2015/2016 international education earned $20.3 billion in export dollars, with universities and other tertiary institutions generating two-thirds of that revenue[147]. In the Times Higher Education 2019 world rankings, six of Australia's Universities are listed as being among the top 100 universities offering engineering programs in the world[148].

The 2018 Employer Satisfaction Survey results[149] are reported to be at their highest level ever suggesting that '*employers remain highly satisfied with graduates from Australia's higher education system*'. In four of the five skills areas Engineering was rated top or near top. However, in 'Employability' Engineering was rated as average. Supervisors also rated well the extent to which the engineering qualification prepared the graduates for their current employment. Appendix 6 provides further details.

In 2017, there were 12,000 Bachelor level graduates in engineering and related technologies. Sixty four percent (7,742) were domestic students[150]. Graduate employment rates and starting salaries for engineers in Australia are consistently higher than those of graduates of other STEM fields. The 2016-17 Bachelor degree graduates in engineering ranked 4th on median starting salary at $64,000, with women earning $1,500 more than men[151]. There was no difference between male and female median starting salaries in 2017[152]. Engineering graduates' from 2017 full-time employment rate was 83%, which is 10% higher than the full-time employment rate for graduates from all fields of education.[153]

Of concern is the relatively low level of engineering graduates' overall satisfaction with their programs of education and teaching in these programs. The Quality Indicators of Learning and

[146] Engineers Australia, Accredited programs https://www.engineersaustralia.org.au/sites/default/files/2018-11/Web_List_V31_181109.pdf
[147] Can the universities of today lead learning for tomorrow? The University of the Future, Ernest and Young
[148] https://www.timeshighereducation.com/world-university-rankings/2019/world-ranking#!/page/0/length/25/sort_by/rank/sort_order/asc/cols/stats
[149] https://www.qilt.edu.au/docs/default-source/ess/ess-2018/2018-ess-national-report-v2.pdf?sfvrsn=9d2ae33c_2
[150] ACED Australian Engineering Education Student, Graduate and Staff Data and Performance Trends February 2019 http://www.aced.edu.au/downloads/ACED%20Engineering%20Statistics%20March%202019.pdf
[151] ACED Australian Engineering Education Facts – Update October 2018 http://www.aced.edu.au/index.php/blog-3/factsheets
[152] ACED Australian Engineering Education Student, Graduate and Staff Data and Performance Trends February 2019 http://www.aced.edu.au/downloads/ACED%20Engineering%20Statistics%20March%202019.pdf
[153] ibid

Teaching (QILT) Graduate Satisfaction data shows[154] that for the 2017 Engineering graduates from undergraduate programs:

(i) Just under half (49.7%) rated their program in the top two points of a 5-point agreement scale on ‘Good Teaching’. This is lowest satisfaction amongst all reported areas of education, but slightly higher than the previous year.

(ii) In contrast, 82.9% gave high ratings to their ‘Generic Skills’ acquisition; higher than the all-field average.

(iii) Although 74.8% rated ‘Overall Satisfaction’ in the top two points of the 5-point agreement scale, this is a lower proportion than other reported areas and the ‘all-fields’ rating.

Also of concern is the declining interest from domestic students in engineering programs. In 2017, engineering took only 5.2% of national commencing Bachelor degree students, the lowest proportion on record[155].

Participation by women and indigenous students continues to be disappointingly low, although the 16.8% figure for 2017 domestic female commencements into Bachelor degrees is the highest on record. Indigenous students account for less than 1% (compared to 2.8% of Australia’s total population). Admission on the basis of secondary school results accounted for 61% of Bachelor commencements in 2017. International students outnumber domestic students by 3:1 in Master programs (both accredited and non-accredited)[156]. Appendix 7 provides further details of recent data on Australian engineering education.

8.2 Recent developments in Australian engineering education

In Australia there has been some recent diversification of engineering education program structures and pathways. The current diversity of programs can be roughly described in terms of varying breadth, technical depth, integration and practice dimensions.

The greatest breadth is being delivered via some double degrees, some of which comprise at least 3 years from the bachelor engineering degree component and 2 – 3 years from the other bachelor degrees. However the breadth is not necessarily contextualized with reference to engineering practice. A broad based bachelor degree followed by postgraduate engineering studies is another ‘double degree’ option.

The greatest technical depth is being delivered via 5 year integrated Bachelor/Master programs and double degrees in engineering and/or closely aligned science and technology.

Integration/systems approaches is a distinctive feature of the Australian National University’s engineering programs.

Practice (WIL) is featured most strongly in the co-op style programs of University of Technology Sydney (UTS), Swinburne, Central Queensland University (CQU) and the new work-based learning bachelor/master dual degree program at Charles Sturt University.

Until 2008 the usual entry to engineering practice pathway was via completion of a 4 year bachelor degree program with some variations on this that offered additional work integrated learning (WIL) components. A number of universities (e.g. UTS, CQU, and Australian Maritime College (AMC)) offered ‘co-operative programs’ that embedded an additional year of WIL in the form of industry internships. The internships are usually recognised with the award of a Diploma of Professional

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[154] ibid
[155] ibid
[156] ibid

Practice. Other universities such as Swinburne University of Technology now also offer such programs. Entry to 'co-op programs' is keenly competitive due to the limited availability of industry placements. At Charles Sturt University a new 5.5 year Bachelor of Technology (Civil Systems)/Master of Engineering (Civil Systems) is being implemented that draws more heavily (for 4 years) on work integrated learning. The work integrated learning is combined with 18 months of on-campus experience framed around a series of project challenges. On-line delivery of technical knowledge and skills is coupled with just-in-time learning.

In 2008 the University of Melbourne (UMelb) discontinued its 4 year Bachelor of Engineering and introduced postgraduate engineering studies as the only degree offering entry to engineering practice. Breadth in the bachelor degree and specialisation in an engineering discipline via graduate school master programs is the distinguishing characteristic of engineering education delivered via the Melbourne Model. This requires the equivalent of a minimum of 5 years of full-time study. The University of Western Australia (UWA) has also implemented a postgraduate entry to practice pathway via the Master of Professional Engineering. Entry to the Master of Professional Engineering requires completion of a Bachelor degree with a major in Engineering Science. Several other universities, including the University of New South Wales and the University of Queensland offer 5 year integrated Bachelor and Master of Engineering programs that provide additional depth in an engineering specialisation.

Many of the 4 year Bachelor (Honours) programs[157] are based on flexible first years that expose students to a range of engineering sciences, introductory level practice courses and allow students to defer a choice of engineering discipline to their second year.

Choices available allow students to select from broadly based area of practice such as civil, chemical, electrical, mechanical engineering, and/or more specialised areas such as naval architecture, metallurgical engineering, petroleum engineering, renewable energy, or biomedical engineering. Systems engineering transcends multiple disciplines and specialisations and is based on an interdisciplinary, whole of life cycle approach that integrates consideration of multiple stakeholder perspectives into the development process for complex projects. The Australian National University is one of the few universities that offer degrees with a focus on and an accompanying qualification title that recognises systems engineering.

The availability of double degrees is also growing with increasing numbers of engineering students enrolling in programs offered in conjunction with business, law, computer science, mathematics, the humanities, and science. At some universities engineering graduates from double degree programs outnumber those from the stand-alone engineering degree. Double degrees that combine engineering with degrees with a creative focus such as design, or innovation are also available at some universities.

Engagement with professional practice is a necessary element of accredited engineering programs in Australia[158]. For programs that do not involve curriculum-based industry internships there is usually a requirement for students to accrue the equivalent of 12 weeks of professional work in order to graduate. ACED's 2016 Position Statement on 'Promoting engagement between industry and

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[157] AQF 2015 resulted in the renaming of the previous 4 year Bachelor of Engineering degrees as Bachelor of Engineering (Honours)

[158] EA https://www.engineersaustralia.org.au/sites/default/files/content-files/2018-01/AMS-STD-10%20Accreditation%20Standard%20-%20Higher%20Education%20v1.0.pdf

universities for engineering graduate capabilities and accelerating innovation'[159] makes several recommendations to universities on how to support better engagement with industry.

Pedagogies in Australian engineering programs are also changing with increasing use being made of 'hands-on' active learning approaches such as work integrated learning, inquiry-based learning, problem and project-based learning, reflective and portfolio based writing. Flipped classrooms are being used to engage students in large classes in collaborative learning[160]. Collaborative design, build and test projects are now widely used in first year introduction to engineering units. Many universities use some form of project-based learning as a practice based or design and/or systems focussed spine for their degree programs.

According to Shulman, signature pedagogies are instrumental in forming habits of mind, prefiguring the cultures of professional work, and providing an early introduction into the practice and values of work[161]. The impact of pedagogy on student learning and achievement must therefore be considered in any review.

An exemplar of learning activities with a focus on human dimensions of engineering are several education programs developed by Engineers Without Borders (EWB) Australia. The EWB Challenge[162] is an Australasian design program for first-year university students coordinated by EWB and delivered in partnership with universities. Implemented nationally in 2007 it has provided opportunities for thousands of students to work in small teams on conceptual designs for sustainable cross-cultural development projects, either as part of the formal curriculum or the extra curriculum. The EWB Humanitarian Design Summits[163] are study tours that provide students with professional work experience drawing on Human-Centred Design and technology to create positive change within communities.

[159] http://www.aced.edu.au/downloads/position_statement_no_1.pdf
[160] https://itali.uq.edu.au/about/projects/flipped-classroom-olt
[161] Signature pedagogies in the professions**,** Shulman, Lee S./*Daedalus;* Summer 2005; 134, 3; Research Library pg. 52
[162] https://ewbchallenge.org/
[163] https://www.ewb.org.au/whatwedo/education-research/designsummit

9. 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'. (TL2)

Notwithstanding the limited extent of consultation undertaken as part of this study, clear messages have 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. (See Recommendation 1: (i – iii)).

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, 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?

   Further work is needed to investigate options to further diversify the Australian engineering education landscape. (See Recommendation 1: (iv – v) and Recommendation 2: (i))

2. T-shaped outcomes will be increasingly valued. Although establishing a much clearer definition of technical expertise and the broader capabilities expected of future engineers will require additional investigation, the following diagram adapted from a presentation by Dr Kourosh Kayvani[164] at the 2017 AAEE conference summarises many of the changes and contexts that have been identified in this study as characterising the work and expectations of future professional engineers.

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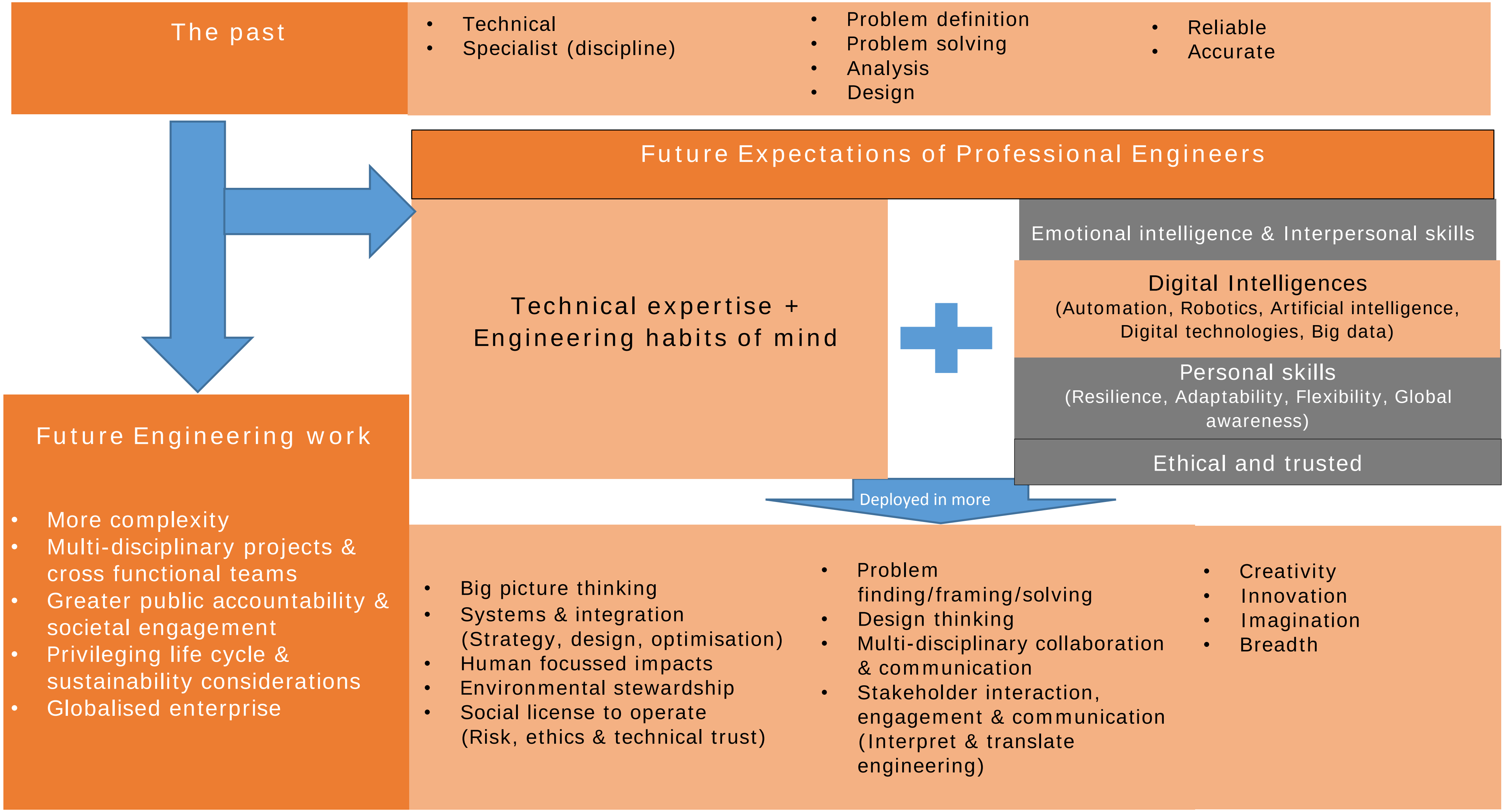
[164] Kourosh Kayvani, The Engineer of 2035, AAEE 2017 conference


The past
Technical
Specialist (discipline)
Problem definition
Problem solving
Analysis
Design
Reliable
Accurate
Future Expectations of Professional Engineers
Technical expertise +
Engineering habits of mind
Emotional intelligence & Interpersonal skills
Digital Intelligences
(Automation, Robotics, Artificial intelligence, Digital technologies, Big data)
Personal skills
(Resilience, Adaptability, Flexibility, Global awareness)
Ethical and trusted
Deployed in more
Future Engineering work
More complexity
Multi-disciplinary projects & cross functional teams
Greater public accountability & societal engagement
Privileging life cycle & sustainability considerations
Globalised enterprise
Big picture thinking
Systems & integration (Strategy, design, optimisation)
Human focussed impacts
Environmental stewardship
Social license to operate (Risk, ethics & technical trust)
Problem finding/framing/solving
Design thinking
Multi-disciplinary collaboration & communication
Stakeholder interaction, engagement & communication (Interpret & translate engineering)
Creativity
Innovation
Imagination
Breadth

Validation 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. Small medium enterprises, micro-companies and start-ups should be included. (See Recommendation 1: (i – iii))

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. (See Recommendation 2)
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. (See Recommendation 2)
5. New kinds of engineering educators will be needed who are more practice-oriented, able to better engage with and inspire students, able to use appropriate pedagogies, and able adapt to the broadening requirements of engineering education. (See Recommendation 3)

No work appears to have been done in Australia on workforce professional engineering planning projections for the future although Engineers Australia is currently conducting a series of round table discussions exploring engineering futures with various industry sectors. Little is known is about the nature of graduate engineers' employment. ACED may wish to explore this further in future work.

Recommendations relating to further work investigating desirable qualities and quantities of graduates are presented in Sections 10.1 of and 10.2 respectively.

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.

10. Recommendations for future work

The following section 10.1 outlines three recommendations for further work for which ACED would be the principal sponsor. These are framed in terms of establishing the knowledge, skills and attributes expected of graduate engineers in 2035 (Recommendation 1), growing the diversity of engineering education programs (Recommendation 2) and greater diversity in the engineering educator workforce (Recommendation 3). Section 10.2 sets out a further three recommendations that ACED may wish to pursue with other organisations as the principal sponsor.

10.1 Recommendations for Engineering Futures 2035 Stage 2.

Stage 2 Recommendation 1 (Graduate Engineers Knowledge, Skills and Attributes)

Extend consultation to explore the perspectives of a broader range of stakeholders to add to and validate the outcomes of the scoping study and in particular the anticipated knowledge, skills and attributes expected of graduate engineers in 2035 and educational priorities for universities contributing to development of these outcomes by:

i. Undertaking further consultation with more industry and government employers and end users to ascertain the nature of their future needs for and expectations of graduate professional engineers. The distinction between professional engineers and other members of the engineering team should also be explored. A challenge will be to cover adequately emerging areas, start-ups and SMEs as well as traditional engineering industries. National engineering research institutes and centres (CSIRO, D61, ANSTO, DSTG, and CRCs) should be included. ACED members' industry advisory committees must also be involved.

ii. Undertaking a national survey of recent engineering graduates to explore their employment contexts, the transition from education into work, and career expectations and ambitions. Graduates view on essential knowledge, skills and attributes needed for their current employment and priorities for change in engineering education that would better meet both their current employment needs and future career aspirations should be canvassed.

iii. Undertaking a national survey of final year engineering students (both bachelor and accredited masters) to explore their educational background, career expectations and ambitions, and perceptions of their programs and their transition to the world of work within and outside engineering.

iv. Undertaking a national survey of students commencing engineering degrees (including the engineering studies streams at The University of Melbourne and University of Western Australia) to understand their background, motivation, expectations and ambitions with reference to choosing to study engineering.

v. Undertaking a detailed national study of equity and diversity in engineering education and graduates' early careers. The increasing diversity of pathways into engineering will need to be examined in detail. Understanding the features in school education and career advice that enable (and inhibit) diversity should also be investigated.

vi. Surveying Deans of Science, Deans of Information and Communications Technology (ACDICT), Australian Business Deans Council (ABDC) and leaders of various Employability Initiatives on future directions to establish potential synergies and alliances.

Confirm and extend the findings of the scoping study to inform further work proposed in recommendations 2 and 3.

Stage 2 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 by:

i. Undertaking consultation with selected engineering educators on new and emerging engineering education programs to provide guidelines and exemplars that may be relevant to the delivery of the range of knowledge, skills and attributes required.
ii. Undertaking a desktop review of global best and emerging practice to develop guidelines and exemplars of new and renewed engineering education programs that can deliver the range of knowledge, skills and attributes required.

Educational philosophy, program structures and pathways, curriculum and pedagogy, assessment, and enabling people, processes and resources would be considered.

Areas of investigation should include

a) Models for the expansion of the current narrow range of program architectures that underpin entry to practice programs available in Australia. Could an engineering education be reimagined as a 'new liberal arts degree' with a problem solving and design focus, mathematics and science foundations, and the development of engineering thinking, judgment and capacity for lifelong learning? What role will double degrees and/or micro credentials play in meeting future education requirements? Should the 4 year Bachelor of Engineering (Honours) be superseded as the dominant education pathway?
b) Approaches emphasising the human dimensions of engineering so that graduates are equipped with a greater understanding and awareness of the potential impact of engineering practice, both good and bad, on human, societal, and environmental needs.
c) Design and implementation of better integrated curriculum employing systems approaches that develop enterprise skills, and interaction and engagement skills in professional practice contexts.
d) Embedding more extensive cross disciplinary, cross institutional and external industry and community engagement in engineering education programs.
e) Use of more experimentation, collaborative pedagogies and open-ended projects/problems in engineering programs.

Embedded curriculum-based practice and student experience is to be the primary focus of this work with particular attention paid to scalability. Exemplars of extracurricular programs could also be provided. Appendix 8 provides further details of a proposed framework.

Recommendations on action by key stakeholders and change management issues, including possible constraints and impediments that will need to be addressed in the Australian context will be developed.

Stage 2 Recommendation 3 (Engineering Educators)

i. Establish the existing engineering educator workforce profiles and desired profile for the engineering educator workforce that can deliver on the required knowledge, skills and attributes by:
    a. Undertaking a survey of the existing engineering educator workforce, to analyse their knowledge, skills and attributes, and

    b. perform a gap analysis against that required to effect curriculum and pedagogic renewal in future engineering education programs.

ii. Undertake 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. This includes practitioners who can engage with students in innovation, entrepreneurship, and design focussed learning.

iii. Propose solutions to modify the engineering educator workforce as indicated by the gap analysis and informed by the desktop review.

10.2 Recommendations for other work

Recommendation 1: ACED continues to engage with and endorse organisations and programs working to improve the public profile and awareness of engineering and its contribution to society and human well-being. The outcomes of any further work on this review that are undertaken by ACED should be promulgated by revising key messages delivered through such work. These should include a stronger emphasis on 'humanising engineering' and using societal impact in relation to improving public perceptions and understanding of engineering.

Recommendation 2: ACED explore with Engineers Australia, ATSE and the Office of the Chief Scientist their interest in undertaking an investigation into the value of engineering to the Australian economy and quantifying its potential to contribute to the nation's future economic growth and prosperity.

Recommendation 3: ACED engages with government, EA and other industry stakeholders to explore their interest in undertaking detailed investigation of the employment experiences of recent engineering graduates that can be used to inform both future engineering workforce and education planning projections and in particular the recalibration of the optimum numbers and diversity of professional engineering graduates entering the Australian workforce following completion of a program of education in Australia.

Appendix 1

List of thought leaders interviewed

Mr Jeroen Buren: General Manager oil and gas; https://www.linkedin.com/in/jeroen-buren-62503918/?originalSubdomain=au

Mrs Hilary Cinis: Data61; Acting Director, Engineering and Design https://people.csiro.au/C/H/Hilary-Cinis

Ms Kathryn Fagg: Boral Board Chair https://scienceandtechnologyaustralia.org.au/profile/kathryn-fagg/

Dr Chris Jeffry: Field Orthopedics and Audeara; CEO, director and innovator https://www.linkedin.com/in/chris-jeffery-b8976451/

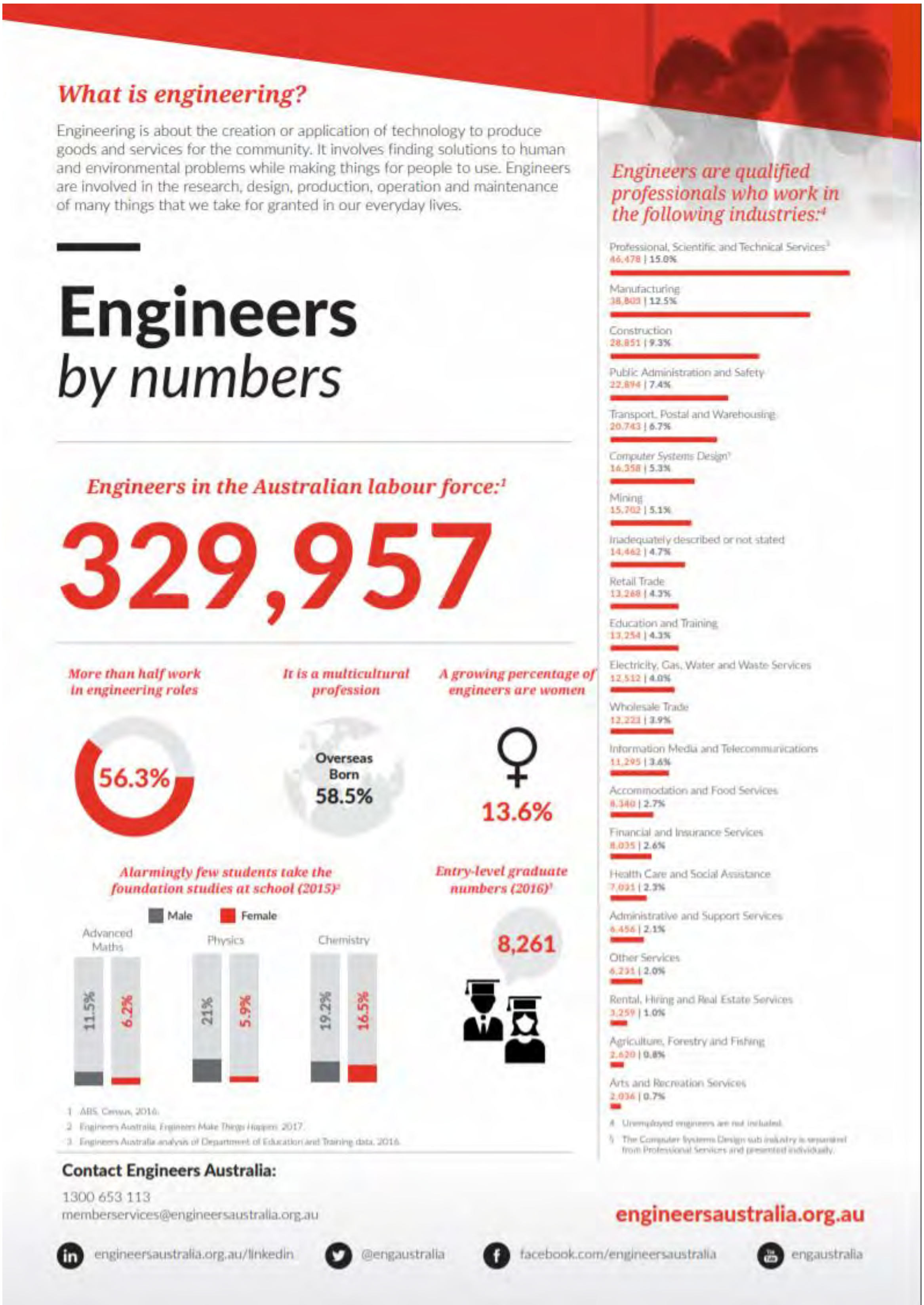
Dr Kourosh Kayvani: Aurecon, Managing Director – Design, Innovation & Eminence https://www.aurecongroup.com/about/aurecon-executive-committee/kourosh-kayvani

Dr Gavin Lind: Minerals Council Australia; Executive Director and Director - Workforce Skills, Health & Safety; Executive Director – MTEC https://sustainableskills.org/gavin-lind-bio/

Mr Bernard Salt: The Demographics Group; Managing Director, Business Advisor and Futurist https://www.bernard-salt.com.au/

Emeritus Professor Elizabeth Taylor: Chair RedR; and International Engineering Alliance Executive Committee (Washington Accord) https://www.engineering.unsw.edu.au/civil-engineering/what-is-engineering/alumni-profiles/alumni-profile-elizabeth-taylor

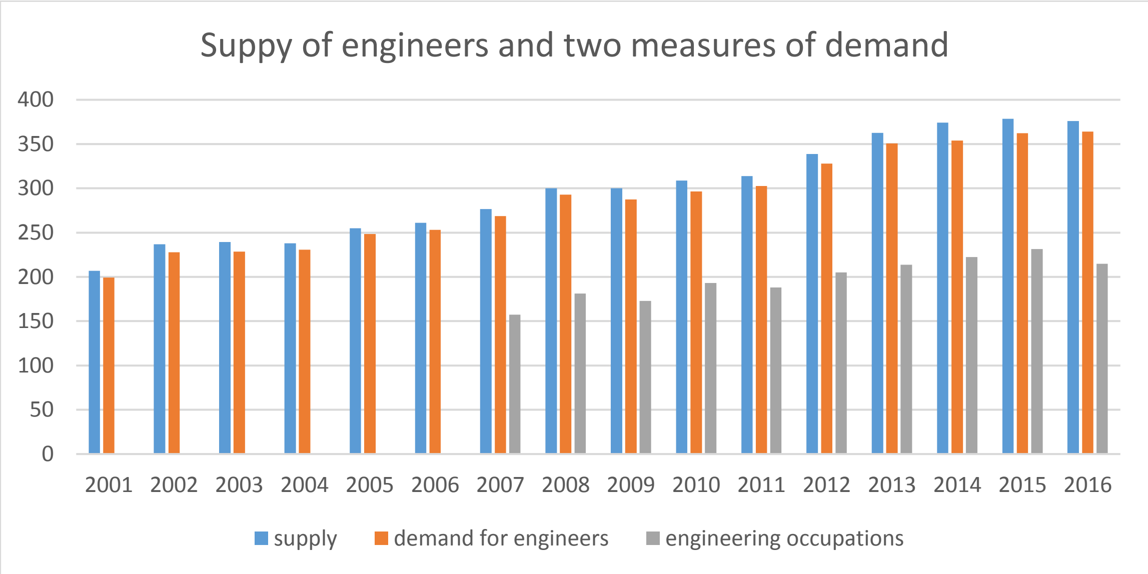
Appendix 2:
Selected EA fast facts from the 2016 census[165]



165 https://www.engineersaustralia.org.au/sites/default/files/resources/Public%20Affairs/2018/EA%20-%20About%20us%20and%20fact%20sheet_0.pdf

EA and ABS longitudinal data on supply and demand for Australia's engineering workforce[166]

The following figure applies to all members of the engineering team and is based on data provided by the Australian Bureau of Statistics drawing on the Labour Force Survey (LFS) and The Survey of Education and Work (SEW). There are two measures of demand used in this analysis i.e. demand for engineers to undertake engineering work as measured by engineers in engineering occupations and demand for engineers to undertake skilled work. The latter is a composite measure of demand for engineers in engineering and other occupations. The demand for engineers to undertake engineering work experienced the greatest decline for the previous decade in 2016. Consequently, the difference between supply and demand for engineers for engineering occupations has increased. However, the gap between supply and overall demand has narrowed.



Other work done by Palmer et al analysing census data and occupational outcomes for engineering[167], science[168], and computer science/IT[169] graduates shows there has been a wide range of employment outcomes outside the occupations traditionally associated with all of these qualifications.

[166] The Engineering Profession Thirteenth Edition, February 2017 https://www.engineersaustralia.org.au/Government-And-Policy/Statistics

[167] S. Palmer, M. Tolson, K. Young & M. Campbell (2015) The relationship between engineering bachelor qualifications and occupational status in Australia, Australasian Journal of Engineering Education, 20:2, 103-112

[168] Occupational Outcomes for Bachelor of Science Graduates in Australia and Implications for Undergraduate Science Curricula, Palmer S, Campbell M, Johnson E, West, J, Res Sci Educ (2018) 48:989–1006

[169] Stuart Palmer, Jo Coldwell-Neilson & Malcolm Campbell (2018) Occupational outcomes for Australian computing/information technology bachelor graduates and implications for the IT bachelor curriculum, Computer Science Education, 28:3, 280-299

Appendix 3

Engineering related industry employment growth projections

Engineering related five year industry employment growth projections[170] are presented in the following table. These projections cover all work within the nominated area.

Department of Jobs and Small Business Industry Projections – five years to May 2023

Industry	Projected employment growth – five years to May 2023	
	('000)	(%)
Agriculture, Forestry and Fishing	-1.4	-0.4
Mining	5.6	2.4
Manufacturing	8.5	0.9
Electricity, Gas, Water and Waste Services	6.1	4.1
Construction	118.8	10.0
Wholesale Trade	-9.7	-2.7
Retail Trade	47.6	3.7
Accommodation and Food Services	81.4	9.1
Transport, Postal and Warehousing	26.9	4.3
Information Media and Telecommunications	10.8	4.7
Financial and Insurance Services	14.2	3.2
Rental, Hiring and Real Estate Services	13.1	5.9
Professional, Scientific and Technical Services	106.6	10.2
Administrative and Support Services	27.9	6.6
Public Administration and Safety	37.7	5.0
Education and Training	113.0	11.2
Health Care and Social Assistance	250.3	14.9
Arts and Recreation Services	22.0	8.7
Other Services	6.9	1.4
All Industries	**886.1**	**7.1**

[170] 2018 Industry Employment Projections Report
http://lmip.gov.au/default.aspx?LMIP/EmploymentProjections

The following table presents the five year projections for the selected engineering and ICT occupations. Strong employment growth for professionals is also forecast for the next 5 years including 21% growth in employment of software and applications programmers, 60% of whom will work in professional services[171].

Department of Jobs and Small Business Occupation projections for selected engineering and ICT occupations – five years to May 2023

Occupation Code	Occupation	Employment level May 2018 ('000)	Department of Jobs and Small Business Projections: Projected employment level May 2023 ('000)	Projected employment growth five years to May 2023 ('000)	Projected employment growth five years to May 2023 (%)
233	*Engineering Professionals*	*149.5*	*157.0*	*7.5*	*5.0*
2331	Chemical and Materials Engineers	7.4	8.2	0.8	11.0
2332	Civil Engineering Professionals	53.3	60.5	7.2	13.5
2333	Electrical Engineers	18.8	18.3	-0.5	-2.6
2334	Electronics Engineers	4.1	3.9	-0.2	-5.0
2335	Industrial, Mechanical and Production Engineers	30.3	28.1	-2.2	-7.2
2336	Mining Engineers	9.5	8.9	-0.5	-5.7
2339	Other Engineering Professionals	14.2	16.6	2.4	17.1
2330	Engineering Professionals nfd	11.6	12.1	0.5	4.5
13	***Specialist Managers***				
1331	Construction Managers	100.9	114.3	13.4	13.3
1332	Engineering Managers	22.9	26.4	3.5	15.2
1351	ICT Managers	58.8	67.0	8.2	13.9
26	***ICT Professionals***	***275.8***	***319.8***	***44.0***	***16.0***
2611	ICT Business and Systems Analysts	23.8	26.1	2.3	9.5
2612	Multimedia Specialists and Web Developers	15.0	18.0	3.1	20.5
2613	Software and Applications Programmers	121.3	146.8	25.5	21.0
2621	Database and Systems Administrators, and ICT Security Specialists	43.9	47.3	3.4	7.6
2631	Computer Network Professionals	31.6	35.2	3.7	11.6
2632	ICT Support and Test Engineers	7.3	8.6	1.3	18.4
2633	Telecommunications Engineering Professionals	15.5	18.5	3.0	19.5
2630	ICT Network and Support Professionals nfd	0.4	0.4	0.1	14.8
2600	ICT Professionals nfd	17.6	19.4	1.8	10.0

[171] Employment Outlook to May 2023, Department of Jobs and Small Business http://lmip.gov.au/default.aspx?LMIP/EmploymentProjections

Appendix 4

EA Stage 1 competencies for professional engineers[172]

ENGINEERS
AUSTRALIA

STAGE 1 COMPETENCY STANDARD FOR PROFESSIONAL ENGINEER

ROLE DESCRIPTION - THE MATURE, PROFESSIONAL ENGINEER

The following characterises the senior practice role that the mature Professional Engineer may be expected to fulfil and has been extracted from the role portrayed in the *Engineers Australia - Chartered Status Handbook*. This is the expectation of the development of the engineer who on graduation satisfied the Stage 1 Competency Standard for Professional Engineer.

Professional Engineers are required to take responsibility for engineering projects and programs in the most far-reaching sense. This includes the reliable functioning of all materials, components, sub-systems and technologies used; their integration to form a complete, sustainable and self-consistent system; and all interactions between the technical system and the context within which it functions. The latter includes understanding the requirements of clients, wide ranging stakeholders and of society as a whole; working to optimise social, environmental and economic outcomes over the full lifetime of the engineering product or program; interacting effectively with other disciplines, professions and people; and ensuring that the engineering contribution is properly integrated into the totality of the undertaking. Professional Engineers are responsible for interpreting technological possibilities to society, business and government; and for ensuring as far as possible that policy decisions are properly informed by such possibilities and consequences, and that costs, risks and limitations are properly understood as the desirable outcomes.

Professional Engineers are responsible for bringing knowledge to bear from multiple sources to develop solutions to complex problems and issues, for ensuring that technical and non-technical considerations are properly integrated, and for managing risk as well as sustainability issues. While the outcomes of engineering have physical forms, the work of Professional Engineers is predominantly intellectual in nature. In a technical sense, Professional Engineers are primarily concerned with the advancement of technologies and with the development of new technologies and their applications through innovation, creativity and change. Professional Engineers may conduct research concerned with advancing the science of engineering and with developing new principles and technologies within a broad engineering discipline. Alternatively, they may contribute to continual improvement in the practice of engineering, and in devising and updating the codes and standards that govern it.

Professional Engineers have a particular responsibility for ensuring that all aspects of a project are soundly based in theory and fundamental principle, and for understanding clearly how new developments relate to established practice and experience and to other disciplines with which they may interact. One hallmark of a professional is the capacity to break new ground in an informed, responsible and sustainable fashion.

Professional Engineers may lead or manage teams appropriate to these activities, and may establish their own companies or move into senior management roles in engineering and related enterprises.

STAGE 1 COMPETENCIES

The three Stage 1 Competencies are covered by 16 mandatory Elements of Competency. The Competencies and Elements of Competency represent the profession's expression of the knowledge and skill base, engineering application abilities, and professional skills, values and attitudes that **must be demonstrated** at the point of entry to practice.

The suggested indicators of attainment in Tables 1, 2 and 3 provide insight to the breadth and depth of ability expected for each element of competency and thus guide the competency demonstration and assessment processes as well as curriculum design. The indicators should not be interpreted as discrete sub-elements of competency mandated for individual audit. Each element of competency must be tested in a holistic sense, and there may well be additional indicator statements that could complement those listed.

Definitions of terms used in the statements of the Competencies and Elements of Competency are consistent with those used by the International Engineering Alliance in Section 4 *Common Range and Contextual Definitions of Graduate Attributes and Professional Competencies Version 3: 21 June 2013.*

[172] https://www.engineersaustralia.org.au/sites/default/files/resource-files/2017-03/Stage%201%20Competency%20Standards.pdf

STAGE 1 COMPETENCIES and ELEMENTS OF COMPETENCY

1. KNOWLEDGE AND SKILL BASE

1.1. **Comprehensive, theory based understanding** of the underpinning natural and physical sciences and the engineering fundamentals applicable to the engineering discipline.

1.2. **Conceptual understanding** of the mathematics, numerical analysis, statistics, and computer and information sciences which underpin the engineering discipline.

1.3. **In-depth understanding** of specialist bodies of knowledge within the engineering discipline.

1.4. **Discernment** of knowledge development and research directions within the engineering discipline.

1.5. **Knowledge** of engineering design practice and contextual factors impacting the engineering discipline.

1.6. **Understanding** of the scope, principles, norms, accountabilities and bounds of sustainable engineering practice in the specific discipline.

2. ENGINEERING APPLICATION ABILITY

2.1. **Application** of established engineering methods to complex engineering problem solving.

2.2. **Fluent application** of engineering techniques, tools and resources.

2.3. **Application** of systematic engineering synthesis and design processes.

2.4. **Application** of systematic approaches to the conduct and management of engineering projects.

3. PROFESSIONAL AND PERSONAL ATTRIBUTES

3.1. **Ethical** conduct and professional accountability.

3.2. **Effective** oral and written communication in professional and lay domains.

3.3. **Creative**, innovative and pro-active demeanour.

3.4. **Professional** use and management of information.

3.5. **Orderly** management of self, and professional conduct.

3.6. **Effective** team membership and team leadership.

Table 1 Knowledge and Skill Base: Elements and Indicators

ELEMENT OF COMPETENCY	INDICATORS OF ATTAINMENT
1.1 Comprehensive, theory based understanding of the underpinning natural and physical sciences and the engineering fundamentals applicable to the engineering discipline.	**a) Engages** with the engineering discipline at a phenomenological level, applying sciences and engineering fundamentals to systematic investigation, interpretation, analysis and innovative solution of *complex* problems and broader aspects of engineering practice.
1.2 Conceptual understanding of the mathematics, numerical analysis, statistics, and computer and information sciences which underpin the engineering discipline.	**a) Develops and fluently applies** relevant investigation analysis, interpretation, assessment, characterisation, prediction, evaluation, modelling, decision making, measurement, evaluation, knowledge management and communication tools and techniques pertinent to the engineering discipline.
1.3 In-depth understanding of specialist bodies of knowledge within the engineering discipline.	**a) Proficiently applies** advanced technical knowledge and skills in at least one specialist practice domain of the engineering discipline.
1.4 Discernment of knowledge development and research directions within the engineering discipline.	**a) Identifies and critically appraises** current developments, advanced technologies, emerging issues and interdisciplinary linkages in at least one specialist practice domain of the engineering discipline. **b) Interprets and applies** selected research literature to inform engineering application in at least one specialist domain of the engineering discipline.
1.5 Knowledge of engineering design practice and contextual factors impacting the engineering discipline.	**a) Identifies and applies** systematic principles of engineering design relevant to the engineering discipline. **b) Identifies and understands** the interactions between engineering systems and people in the social, cultural, environmental, commercial, legal and political contexts in which they operate, including both the positive role of engineering in sustainable development and the potentially adverse impacts of engineering activity in the engineering discipline. **c) Appreciates** the issues associated with international engineering practice and global operating contexts. **d) Is aware of** the founding principles of human factors relevant to the engineering discipline. **e) Is aware of** the fundamentals of business and enterprise management. **f) Identifies** the structure, roles and capabilities of the engineering workforce.
1.6 Understanding of the scope, principles, norms, accountabilities and bounds of sustainable engineering practice in the specific discipline.	**a) Appreciates** the basis and relevance of standards and codes of practice, as well as legislative and statutory requirements applicable to the engineering discipline. **b) Appreciates** the principles of safety engineering, risk management and the health and safety responsibilities of the professional engineer, including legislative requirements applicable to the engineering discipline. **c) Appreciates** the social, environmental and economic principles of sustainable engineering practice. **d) Understands** the fundamental principles of engineering project management as a basis for planning, organising and managing resources. **e) Appreciates** the formal structures and methodologies of systems engineering as a holistic basis for managing complexity and sustainability in engineering practice.

Notes:

1. *'engineering discipline' means the broad branch of engineering (civil, electrical, mechanical, etc.) as typically represented by the Engineers Australia Colleges.*
2. *'specialist practice domain' means the specific area of knowledge and practice within an engineering discipline, such as geotechnics, power systems, manufacturing, etc.*

<u>Table 2</u> Engineering Application Ability: Elements and Indicators

ELEMENT OF COMPETENCY	INDICATORS OF ATTAINMENT
2.1 **Application** of established engineering methods to *complex* engineering problem solving.	a) **Identifies, discerns and characterises** salient issues, **determines and analyses** causes and effects, **justifies and applies** appropriate simplifying assumptions, **predicts** performance and behaviour, **synthesises** solution strategies and **develops** substantiated conclusions. b) **Ensures** that all aspects of an engineering activity are soundly based on fundamental principles - by diagnosing, and taking appropriate action with data, calculations, results, proposals, processes, practices, and documented information that may be ill-founded, illogical, erroneous, unreliable or unrealistic. c) **Competently addresses** complex engineering problems which involve uncertainty, ambiguity, imprecise information and wide-ranging and sometimes conflicting technical and non-technical factors. d) **Investigates** complex problems using research-based knowledge and research methods. e) **Partitions** problems, processes or systems into manageable elements for the purposes of analysis, modelling or design and then **re-combines** to form a whole, with the integrity and performance of the overall system as the paramount consideration. f) **Conceptualises** alternative engineering approaches and **evaluates** potential outcomes against appropriate criteria to justify an optimal solution choice. g) **Critically reviews and applies** relevant standards and codes of practice underpinning the engineering discipline and nominated specialisations. h) **Identifies, quantifies, mitigates and manages** technical, health, environmental, safety and other contextual risks associated with engineering application in the designated engineering discipline. i) **Interprets and ensures** compliance with relevant legislative and statutory requirements applicable to the engineering discipline.
2.2 **Fluent application** of engineering techniques, tools and resources.	a) **Proficiently identifies, selects and applies** the materials, components, devices, systems, processes, resources, plant and equipment relevant to the engineering discipline. b) **Constructs or selects and applies** from a qualitative description of a phenomenon, process, system, component or device a mathematical, physical or computational model based on fundamental scientific principles and justifiable simplifying assumptions. c) **Determines** properties, performance, safe working limits, failure modes, and other inherent parameters of materials, components and systems relevant to the engineering discipline. d) **Applies** a wide range of engineering tools for analysis, simulation, visualisation, synthesis and design, including assessing the accuracy and limitations of such tools, and validation of their results. e) **Applies** formal systems engineering methods to address the planning and execution of complex, problem solving and engineering projects. f) **Designs and conducts** experiments, **analyses and interprets** result data and **formulates** reliable conclusions. g) **Analyses** sources of error in applied models and experiments; eliminates, **minimises or compensates** for such errors; **quantifies** significance of errors to any conclusions drawn. h) **Safely applies** laboratory, test and experimental procedures appropriate to the engineering discipline. i) **Understands** the need for systematic management of the acquisition, commissioning, operation, upgrade, monitoring and maintenance of engineering plant, facilities, equipment and systems. j) **Understands** the role of quality management systems, tools and processes within a culture of continuous improvement.

Table 2 (cont.) Engineering Application Ability: Elements and Indicators

ELEMENT OF COMPETENCY	INDICATORS OF ATTAINMENT
2.3 **Application** of systematic engineering synthesis and design processes.	**a) Proficiently applies** technical knowledge and open ended problem solving skills as well as appropriate tools and resources to design components, elements, systems, plant, facilities and/or processes to satisfy user requirements. **b) Addresses** broad contextual constraints such as social, cultural, environmental, commercial, legal political and human factors, as well as health, safety and sustainability imperatives as an integral part of the design process. **c) Executes and leads** a whole systems design cycle approach including tasks such as: - determining client requirements and identifying the impact of relevant contextual factors, including business planning and costing targets; - systematically addressing sustainability criteria; - working within projected development, production and implementation constraints; - eliciting, scoping and documenting the required outcomes of the design task and defining acceptance criteria; - identifying assessing and managing technical, health and safety risks integral to the design process; - writing engineering specifications, that fully satisfy the formal requirements; - ensuring compliance with essential engineering standards and codes of practice; - partitioning the design task into appropriate modular, functional elements; that can be separately addressed and subsequently integrated through defined interfaces; - identifying and analysing possible design approaches and justifying an optimal approach; - developing and completing the design using appropriate engineering principles, tools, and processes; - integrating functional elements to form a coherent design solution; - quantifying the materials, components, systems, equipment, facilities, engineering resources and operating arrangements needed for implementation of the solution; - checking the design solution for each element and the integrated system against the engineering specifications; - devising and documenting tests that will verify performance of the elements and the integrated realisation; - prototyping/implementing the design solution and verifying performance against specification; - documenting, commissioning and reporting the design outcome. **d) Is aware of** the accountabilities of the professional engineer in relation to the 'design authority' role.
2.4 **Application** of systematic approaches to the conduct and management of engineering projects.	**a) Contributes to and/or manages** *complex* engineering project activity, as a member and/or as the leader of an engineering team. **b) Seeks out** the requirements and associated resources and **realistically assesses** the scope, dimensions, scale of effort and indicative costs of a *complex* engineering project. **c) Accommodates** relevant contextual issues into all phases of engineering project work, including the fundamentals of business planning and financial management **d) Proficiently applies** basic systems engineering and/or project management tools and processes to the planning and execution of project work, targeting the delivery of a significant outcome to a professional standard. **e) Is aware of** the need to plan and quantify performance over the full life-cycle of a project, managing engineering performance within the overall implementation context. **f) Demonstrates** commitment to sustainable engineering practices and the achievement of sustainable outcomes in all facets of engineering project work.

Table 3 Professional and Personal Attributes: Elements and Indicators

ELEMENT OF COMPETENCY	INDICATORS OF ATTAINMENT
3.1 **Ethical** conduct and professional accountability.	a) **Demonstrates** commitment to uphold the Engineers Australia - Code of Ethics, and established norms of professional conduct pertinent to the engineering discipline. b) **Understands** the need for 'due-diligence' in certification, compliance and risk management processes. c) **Understands** the accountabilities of the professional engineer and the broader engineering team for the safety of other people and for protection of the environment. d) **Is aware of** the fundamental principles of intellectual property rights and protection.
3.2 **Effective** oral and written communication in professional and lay domains.	a) **Is proficient in** listening, speaking, reading and writing English, including: - comprehending critically and fairly the viewpoints of others; - expressing information effectively and succinctly, issuing instruction, engaging in discussion, presenting arguments and justification, debating and negotiating - to technical and non-technical audiences and using textual, diagrammatic, pictorial and graphical media best suited to the context; - representing an engineering position, or the engineering profession at large to the broader community; - appreciating the impact of body language, personal behaviour and other non-verbal communication processes, as well as the fundamentals of human social behaviour and their cross-cultural differences. b) **Prepares** high quality engineering documents such as progress and project reports, reports of investigations and feasibility studies, proposals, specifications, design records, drawings, technical descriptions and presentations pertinent to the engineering discipline.
3.3 **Creative**, innovative and pro-active demeanour.	a) **Applies** creative approaches to identify and develop alternative concepts, solutions and procedures, appropriately challenges engineering practices from technical and non-technical viewpoints; identifies new technological opportunities. b) **Seeks out** new developments in the engineering discipline and specialisations and **applies** fundamental knowledge and systematic processes to evaluate and report potential. c) **Is aware of** broader fields of science, engineering, technology and commerce from which new ideas and interfaces may be drawn and readily **engages** with professionals from these fields to exchange ideas.
3.4 **Professional** use and management of information.	a) **Is proficient in** locating and utilising information - including accessing, systematically searching, analysing, evaluating and referencing relevant published works and data; is proficient in the use of indexes, bibliographic databases and other search facilities. b) **Critically assesses** the accuracy, reliability and authenticity of information. c) **Is aware of** common document identification, tracking and control procedures.
3.5 **Orderly** management of self, and professional conduct.	a) **Demonstrates** commitment to critical self-review and performance evaluation against appropriate criteria as a primary means of tracking personal development needs and achievements. b) **Understands** the importance of being a member of a professional and intellectual community, learning from its knowledge and standards, and contributing to their maintenance and advancement. c) **Demonstrates** commitment to life-long learning and professional development. d) **Manages** time and processes effectively, **prioritises** competing demands to achieve personal, career and organisational goals and objectives. e) **Thinks critically and applies** an appropriate balance of logic and intellectual criteria to analysis, judgement and decision making. f) **Presents** a professional image in all circumstances, including relations with clients, stakeholders, as well as with professional and technical colleagues across wide ranging disciplines.
3.6 **Effective** team membership and team leadership.	a) **Understands** the fundamentals of team dynamics and leadership. b) **Functions as** an effective member or leader of diverse engineering teams, including those with multi-level, multi-disciplinary and multi-cultural dimensions. c) **Earns** the trust and confidence of colleagues through competent and timely completion of tasks. d) **Recognises** the value of alternative and diverse viewpoints, scholarly advice and the importance of professional networking. e) **Confidently pursues and discerns** expert assistance and professional advice. f) **Takes initiative and fulfils** the leadership role whilst respecting the agreed roles of others.

Appendix 5

Knowledge, Skills and Attributes from TUEE (USA)

The following list of 36 Knowledge, Skills and Abilities were identified as important in engineering education by the Transforming Undergraduate Engineering Education project Phase I: Synthesizing and Integrating Industry Perspectives Workshop and reported as outcomes of a May 9-10, 2013 workshop sponsored by ASEE and NSF[173]. The workshop was attended by 34 invited representatives from a range of companies.

KSA 1: Good communication skills (skill)
KSA 2: Physical sciences and engineering science fundamentals (knowledge)
KSA 3: Ability to identify, formulate, and solve engineering problems (skill)
KSA 4: Systems integration (knowledge)
KSA 5: Curiosity and persistent desire for continuous learning (ability)
KSA 6: Self-drive and motivation (ability)
KSA 7: Cultural awareness in the broad sense: nationality, ethnicity, linguistic, gender, sexual orientation (knowledge)
KSA 8: Economics and business acumen (knowledge)
KSA 9: High ethical standards, integrity, and global, social, intellectual, and technological responsibility (ability)
KSA 10: Critical thinking (skill)
KSA 11: Willingness to take calculated risk (ability)
KSA 12: Ability to prioritize efficiently (skill)
KSA 13: Project management: supervising, planning, scheduling, budgeting, etc. (skill)
KSA 14: Teamwork skills and ability to function on multidisciplinary teams (ability)
KSA 15: Entrepreneurship and intrapreneurship (ability)
KSA 16: Ability to use new technology and modern engineering tools necessary for engineering practice (skill)
KSA 17: Public safety (knowledge)
KSA 18: Informational technology – IT (knowledge)
KSA 19: Applied knowledge of engineering core sciences and implementation skills to apply them in the real world (skill)
KSA 20: Data interpretation and visualization (skill)
KSA 21: Security knowledge: cyber, data, etc. (knowledge)
KSA 22: Leadership (skill)
KSA 23: Creativity (ability)
KSA 24: Systems thinking (skill)
KSA 25: Emotional intelligence (ability)
KSA 26: Application-based research and evaluation skills (skill)
KSA 27: Ability to create a vision (skill)
KSA 28: Good personal and professional judgment (ability)
KSA 29: Mentoring skills (skill)
KSA 30: Flexibility and the ability to adapt to rapid change (ability)
KSA 31: Ability to deal with ambiguity and complexity (skill)
KSA 32: Innovation (ability)
KSA 33: Technical intuition/metacognition (ability)
KSA 34: Understanding of design (knowledge)
KSA 35: Conflict resolution (knowledge)
KSA 36: Ownership and accountability (ability)

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[173] https://www.asee.org/TUEE_PhaseI_WorkshopReport.pdf

Appendix 6

Selected 2018 Employer Satisfaction Survey results

The 2018 Employer Satisfaction Survey results[174] are reported to be at their highest level ever suggesting that '*employers remain highly satisfied with graduates from Australia's higher education system*'. The first table below reports the outcomes for selected broad fields of study in terms of employer satisfaction with graduates overall and in five graduate attribute domains. The second table reports graduate and supervisor perceptions of the extent to which qualification prepared the graduate well or very well for the graduate's current employment.

The 2018 Employer Satisfaction Survey recruited 'employer' respondents by asking graduates to nominate their supervisor. As volunteers, those who responded were likely to be well disposed towards the graduates. 86.9% of employers rated Engineering graduates in the top two points of a 5-point agreement scale for 'Overall Satisfaction', higher than the rating for 'all fields', but lower than for last year. In three of the skills areas (Foundation, Collaborative and Technical), Engineering was rated close to or better than 'all fields'. For 'Adaptive' and 'Employability', Engineering was rated lower than 'all fields'. These supervisors rated the importance of the qualification highly, and rated well the extent to which it had prepared the graduates for their current employment.

Employer Satisfaction Survey – skills areas, 2018, selected fields of education. Data are percentages of employers expressing agreement or strong agreement with a relevant statement on graduate skills. Previous year data in parentheses.[175]

Field of education	Foundation	Adaptive	Collaborative	Technical	Employability	Overall satisfaction
2016 All fields	92.0	88.4	84.6	92.2	83.8	84.3
2017 All fields	93.4	90.1	85.9	93.3	85.0	83.6
2018 All fields	**93.5**	**89.9**	**88.7**	**93.8**	**86.5**	**84.8**
Engineering & Related Technologies	**95.0 (95.6)**	**88.3 (90.8)**	**88.6 (88.7)**	**94.4 (95.7)**	**83.3 (85.0)**	**86.9 (89.9)**
Natural & Physical Sciences	97.3 (94.6)	90.9 (89.3)	88.6 (88.0)	96.3 (94.5)	89.4 (85.7)	87.0 (80.1)
Information Technology	92.9 (95.1)	89.7 (91.1)	90.5 (90.4)	94.4 (95.5)	84.6 (85.7)	87.2 (82.1)
Health	93.5 (93.6)	89.1 (88.8)	88.6 (86.3)	93.9 (94.6)	84.8 (84.3)	86.6 (88.6)
Management & Commerce	92.8 (92.5)	88.4 (91.0)	87.4 (84.7)	92.0 (91.7)	88.2 (86.1)	83.4 (79.8)

Employer Satisfaction Survey – importance ratings by graduates and their supervisors, 2018, selected fields of education. Previous year data in parentheses.

Field of education	% of respondents rating qualification 'important' or 'very important'		% of respondents rating 'well' or 'very well' the extent to which qualification prepared graduates	
	Graduates	Supervisors	Graduates	Supervisors
All fields	**56.5 (56.3)**	**63.8 (63.8)**	**88.1 (88.2)**	**92.1 (93.2)**
Engineering & Related Technologies	**59.2 (59.6)**	**67.7 (70.9)**	**89.0 (89.3)**	**92.3 (94.9)**
Natural & Physical Sciences	46.7 (50.2)	61.5 (45.2)	84.2 (85.4)	91.0 (90.1)
Information Technology	47.8 (41.0)	45.3 (34.5)	85.4 (84.5)	91.6 (93.0)
Health	74.2 (72.6)	79.3 (78.9)	92.5 (90.8)	93.4 (94.0)
Management & Commerce	39.1 (40.2)	49.4 (47.6)	87.3 (89.6)	91.3 (92.7)

[174] https://www.qilt.edu.au/docs/default-source/ess/ess-2018/2018-ess-national-report-v2.pdf?sfvrsn=9d2ae33c_2

[175] ACED Australian Engineering Education Student, Graduate and Staff Data and Performance Trends March 2019 http://www.aced.edu.au/downloads/ACED%20Engineering%20Statistics%20March%202019.pdf

The following two tables show the data from the 2018 report[176] for all fields and the confidence intervals.

	Foundation		Adaptive		Collaborative		Technical		Employability		Overall satisfaction	
	%	CI	%	CI	%	CI	%	CI	%	CI	%	CI
Natural and Physical Sciences	97.3	(95.7, 98.4)	90.9	(88.2, 93.0)	93.0	(90.7, 94.8)	96.3	(94.4, 97.6)	89.4	(86.6, 91.7)	87.0	(84.0, 89.5)
Information Technology	92.9	(89.2, 95.4)	89.7	(85.5, 92.8)	90.5	(86.5, 93.4)	94.4	(91.0, 96.6)	84.6	(79.7, 88.5)	87.2	(82.7, 90.6)
Engineering and Related Technologies	95.0	(92.7, 96.6)	88.3	(85.2, 90.8)	88.6	(85.6, 91.1)	94.4	(91.9, 96.1)	83.3	(79.7, 86.4)	86.9	(83.7, 89.6)
Architecture and Building	92.7	(87.4, 96.0)	86.5	(80.2, 91.0)	91.8	(86.3, 95.3)	92.7	(87.4, 96.0)	86.0	(79.5, 90.7)	87.3	(81.1, 91.7)
Agriculture and Environmental Studies	94.6	(89.8, 97.4)	91.1	(85.5, 94.7)	89.4	(83.6, 93.3)	94.7	(89.9, 97.4)	89.9	(84.1, 93.8)	88.7	(82.8, 92.8)
Health	93.5	(92.2, 94.6)	89.1	(87.6, 90.5)	88.6	(87.0, 90.0)	93.9	(92.6, 94.9)	84.8	(83.0, 86.4)	86.6	(84.9, 88.1)
Education	93.4	(91.7, 94.7)	92.5	(90.7, 93.9)	86.1	(83.9, 88.0)	95.1	(93.6, 96.2)	87.0	(84.9, 88.9)	85.8	(83.5, 87.7)
Management and Commerce	92.8	(91.3, 94.1)	88.4	(86.5, 90.0)	87.4	(85.4, 89.1)	92.0	(90.3, 93.3)	88.2	(86.3, 89.9)	83.4	(81.3, 85.4)
Society and Culture	93.5	(92.1, 94.7)	91.2	(89.6, 92.6)	89.2	(87.4, 90.7)	93.6	(92.2, 94.7)	87.3	(85.4, 88.9)	81.7	(79.6, 83.6)
Creative Arts	92.0	(88.6, 94.5)	88.4	(84.5, 91.4)	90.2	(86.7, 93.0)	93.2	(90.0, 95.5)	85.3	(81.0, 88.7)	81.4	(77.0, 85.1)
Total	**93.5**	**(92.9, 94.1)**	**89.9**	**(89.2, 90.6)**	**88.7**	**(87.9, 89.4)**	**93.8**	**(93.3, 94.4)**	**86.5**	**(85.7, 87.3)**	**84.8**	**(84.0, 85.6)**

	Graduates		Supervisors	
	%	CI	%	CI
Natural and Physical Sciences	84.2	(80.9, 87.1)	91.0	(88.3, 93.1)
Information Technology	85.4	(80.8, 89.1)	91.6	(87.6, 94.4)
Engineering and Related Technologies	89.0	(85.9, 91.5)	92.3	(89.6, 94.3)
Architecture and Building	85.6	(79.2, 90.3)	84.5	(78.0, 89.4)
Agriculture and Environmental Studies	86.0	(79.5, 90.7)	90.8	(85.1, 94.5)
Health	92.5	(91.2, 93.7)	93.4	(92.1, 94.5)
Education	92.4	(90.7, 93.9)	95.2	(93.7, 96.4)
Management and Commerce	87.3	(85.3, 89.0)	91.3	(89.6, 92.8)
Society and Culture	82.8	(80.6, 84.7)	91.4	(89.8, 92.8)
Creative Arts	84.3	(80.0, 87.9)	90.3	(86.6, 93.1)
Food, Hospitality and Personal Services	0.0	0.0	0.0	0.0
Total	**88.1**	**(87.4, 88.9)**	**92.1**	**(91.4, 92.7)**
Standard deviation	3.4		2.7	

176 https://www.qilt.edu.au/docs/default-source/ess/ess-2018/2018-ess-national-report-v2.pdf?sfvrsn=9d2ae33c_2

Appendix 7:

Selected ACED Statistics [177]

KEY FACTS FOR ENGINEERING & RELATED TECHNOLGIES - 2017

SYSTEM SIZE

Total enrolment: 115,420 students (111,605 at the 36 ACED member institutions)
Student load: 75,865 EFTS (effective full-time students) at the ACED institutions
Academic staff: ~ 4,200 FTE (excl'g casuals) in teaching and research positions at ACED institutions.

GRADUATES

award	domestic (% women)	international (% women)
Bachelors degrees	7,742 (14.9%)	4,301 (20.3%)
Postgraduate coursework	2,135 (21.1%)	4,894 (17.3%)
Research (PhD and Masters)	742 (24.5%)	901 (26.8%)
Other undergraduate awards	784 (9.0%)	1,264 (13.1%)

Approximate distributions amongst major branches of engineering for graduates of Bachelors Degrees (including Honours) and Associate Degrees and Advanced Diplomas:

branch of engineering	domestic (% women)	international (% women)
aerospace (inc. civil aviation)	11% (15%)	9% (27%)
civil engineering	30% (12%)	25% (18%)
electrical & electronics	18% (9%)	25% (16%)
mechanical & manufacturing	21% (8%)	25% (9%)
process & resources (chemical & mining)	14% (28%)	11% (40%)
other	6% (nd)	5% (nd)

For holders of undergraduate awards, 6 months after graduation:

measure surveyed	engineering	all fields
median salary	**$65,000**	$61,500
in full-time employment	**83.1%**	72.9%
graduate overall satisfaction	**74.9%**	79.7%
employer overall satisfaction	**86.9%**	84.8%

More than 75% of the graduates of a Bachelors degree in Engineering are likely to have commenced higher education study in the same institution, up to 6 years earlier.

COMMENCEMENTS

award	domestic (% women)	international (% women)
Bachelors degrees	13,736 (16.9%)	7,842 (20.3%)
Postgraduate coursework	2,525 (17.8%)	8,279 (20.1%)
Research (PhD and Masters)	888 (25.2%)	1,632 (27.3%)
Other undergraduate awards	1,662 (12.3%)	1,917 (13.4%)

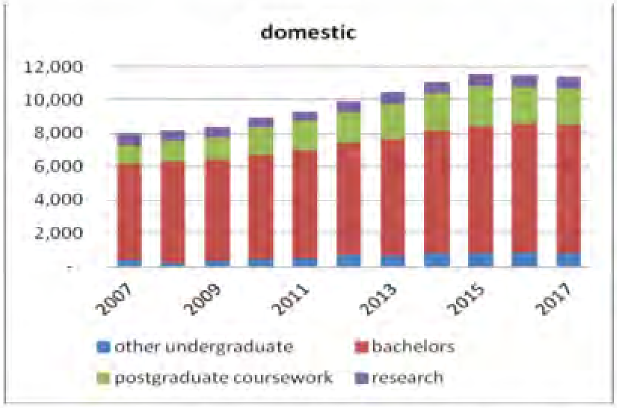
Engineering enrolled 5.2% of all domestic commencing students commencing Bachelors Degrees. This proportion has declined steadily since being 6.0% in 2013.

62% of the domestic students commencing Bachelors degrees (including Honours), entered from school on the basis of ATAR. **70% of this group had ATAR greater than 80.00**. (For all fields of education the equivalent figures are 40% and 48.1%, respectively.) Engineering is consistently the field of education with the strongest ATAR profile, and the highest rate of school-leaver entry. .

More than 75% of domestic students who commence a Bachelors degree in Engineering are likely to complete a degree, in Engineering or another field.

[177] ACED Australian Engineering Education Student, Graduate and Staff Data and Performance Trends March 2019 http://www.aced.edu.au/downloads/ACED%20Engineering%20Statistics%20March%202019.pdf

Graduations by award level



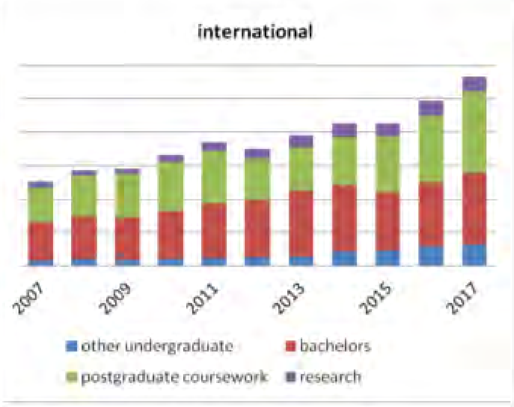
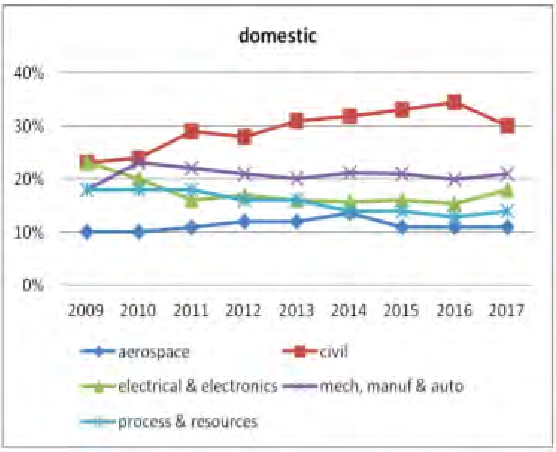


Figure 1 Domestic and international student graduations, 2007-17

Undergraduate completions by branch of engineering



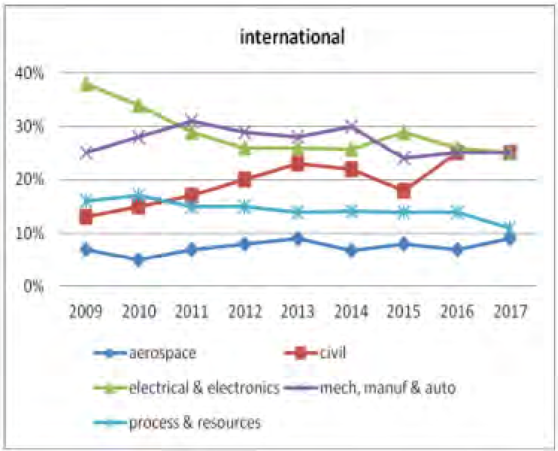
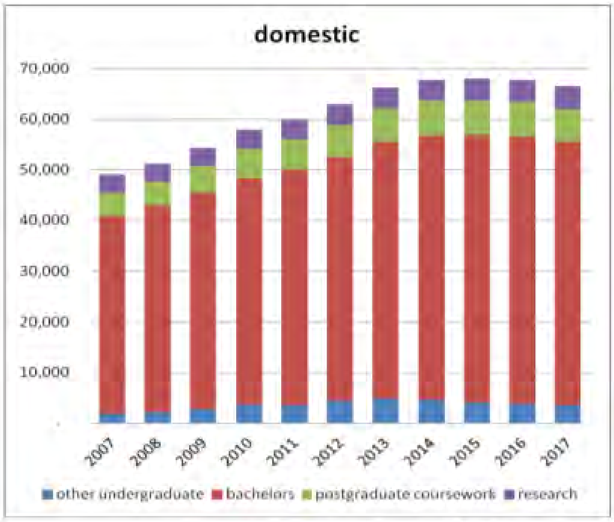


Figure 2 Indicative distributions of undergraduate awards by branch of engineering, 2009-17

Total enrolments



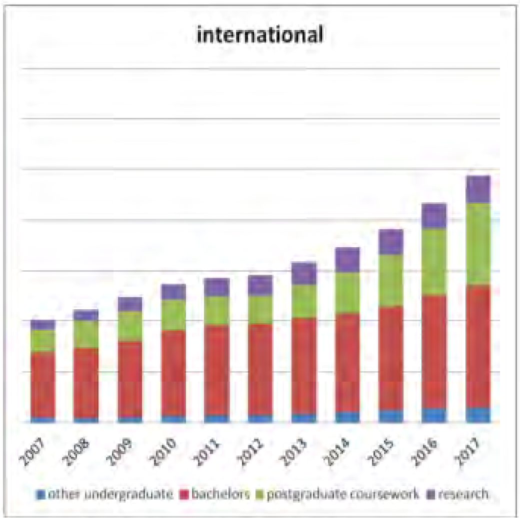


Figure 3 Domestic and international student enrolments, 2007-17

Commencing enrolments

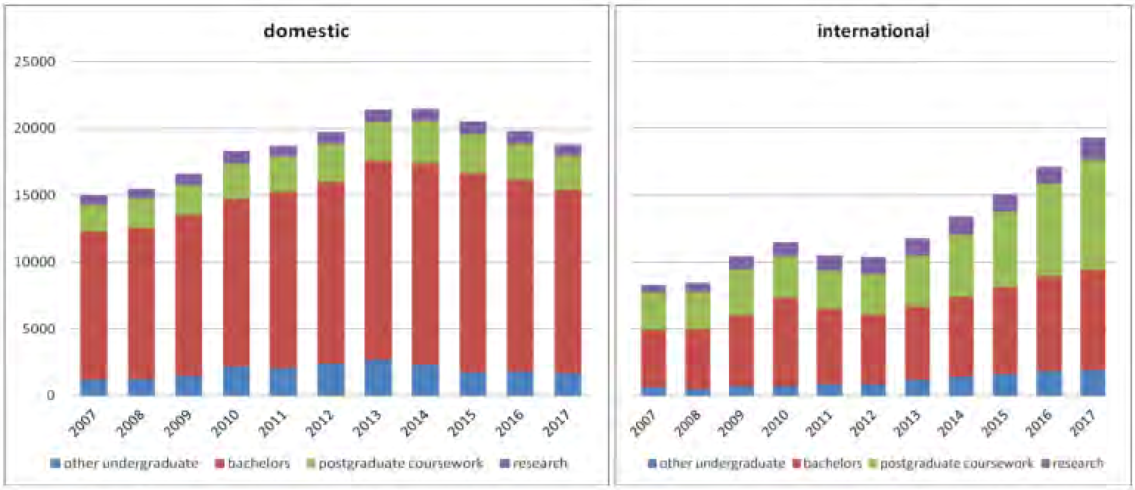


Figure 4 Domestic and international student commencing enrolments, 2007-17

Appendix 8

Proposed Framework for developing Stage 2 outcomes from Recommendations 2 and 3

The outcomes of work proposed by recommendation 2 will be framed as a set of guidelines on how student engineers can be provided with learning experiences that will equip them with knowledge, skills and attributes for entry to professional practice that meets future needs including those identified by the scoping study in conjunction with the outcomes of further work proposed by Recommendation 1.

a) **Outline the nature and scope of educational programs needed to prepare graduates with required knowledge skills and attributes to meet future industry needs**. Suggested framing in terms of desirable student engineer experiences including:
   i. Educational Philosophy e.g. framing of engineering as
      i. a vehicle for positive world change
      ii. Multi-disciplinary
      iii. Breadth
      iv. Development of professional skills and attitudes
      v. Application to practice
   ii. Program structures and pathways including: e.g.
      i. Diversity of models
      ii. Choice and flexibility
      iii. Students as partners
   iii. Curriculum and context: e.g.
      i. Design and maker based
      ii. Project centred curriculum
      iii. Academic rigour in engineering fundamentals
      iv. Close industry partnerships
      v. External engagement – industry and community
   iv. Pedagogy: e.g.
      i. Collaborative cultures – supporting small group learning
      ii. Student centred active learning
      iii. Student led learning
      iv. Self-directed learning
      v. Blended learning
      vi. Flexible, on-line learning
      vii. Research /discovery based, and just in time learning
      viii. Flipped classrooms
   v. Authentic assessments: e.g.
      i. Industry based
      ii. Simulated scenarios
      iii. Across the full range of graduate competencies
      iv. Increased use of reflection
   vi. Enabling people, processes, systems and resources

b) **Identify exemplars of a range of best practices**

c) **Managing change**
   i. Identifies required participants in effecting change
   ii. Identifies likely constraints and impediments e.g.
      i. Scalability

ii. Accreditation and State registration authorities. Accreditation issues, particularly during an experimentation phase; EA needs to be involved in supporting innovative and experimental programs
iii. Academic and teaching staff capabilities that are current re industry needs. Many academic staff do not have any or current industry experience.
    1. A shift in the style of engineering education away from a dominance of engineering science to more engineering practice will require a more diverse academic and better representative of industry workforce (Recommendation 3 addresses this)
iv. Industry engagement in academic environments – this will be critical in addressing iii
v. Funding – cannot expect more Government funding. How is experimentation to be funded? Any application to government will need to be broad and with transferability to other areas so that benefits of any work are seen as being widely applicable. Connections with funding of STEM pipeline?

b) **Recommendations for action**: these will be grouped and targeted to specific audiences including:
i. Australian Engineering Schools
ii. Engineers Australia Accreditation
iii. ACED re sharing best practice and disseminating case studies of how to do it
iv. Australian Government
v. Industry