ACED
AUSTRALIAN COUNCIL OF ENGINEERING DEANS

Engineering change

The future of engineering education in Australia

Engineering 2035 Project

This report has been distilled
from four major reports for ACED.
They can be found online at:
aced.edu.au/index.php/blog-3/reports

FOREWORD

The challenge of change

It is 12 years since the last major review of professional engineering education in Australia. We set out to examine the "what", "how" and "who" of preparing the engineers of tomorrow, recognising that we will have to begin making the changes required now. In examining this issue, we recognise that the education of the past has served the nation well. However, significant changes are occurring in work practices, in the way we solve problems, and in society's role in identifying and proposing solutions. Today's challenges cannot be overcome by technical prowess alone.

What then are the competencies required of a professional engineer operating in this new environment? Employers of professional engineers have clear views: they want engineers who can work in multi-disciplinary teams; have emotional intelligence (including empathy) and high-level communication skills; are adept at problem finding, systems thinking, and are digital/data savvy; have technical expertise (or can acquire it as the needs arise); and who can solve problems.

To meet industry's expectations, students need greater exposure to engineering practice during their undergraduate programs. Overseas experience demonstrates the multiple ways this can be achieved in Australian engineering schools. But no single model will work for all institutions: schools will need to define their expected student outcomes, then select the model that best suits their needs and circumstances.

Academic staff will be at the forefront of delivering this new approach to curriculum and pedagogy. In the past year they have demonstrated remarkable willingness to change their teaching practices in response to the new COVID environment, adapting quickly to online delivery, and willing to further adapt the curriculum. They understand industry's desire to have students exposed more to industrial practice. They also want to be supported to do this, which may require appointing additional staff with relevant industrial experience.

Potential students seeking to study in this new environment must be better informed of the exciting breadth of modern engineering practice and appreciate the greater emphasis on the human elements of engineering. This matches well their desire to "make a difference in society".

Emeritus Professor Peter L Lee FTSE, FIEAust.
Chair, Steering Committee

This report was commissioned by the Australian Council of Engineering Deans and over the course of the investigation was guided and conducted by (in alphabetical order):

Professor Ian Burnett

Emeritus Professor Ian Cameron

Emeritus Professor Caroline Crosthwaite

Ms Bernadette Foley

Dr Tom Goldfinch

Professor Roger Hadgraft

Emeritus Professor Doug Hargreaves AM

Emeritus Professor Robin King

Professor Julia Lamborn

Mr Rob Lawrence

Honorary Associate Professor Carl Reidsema

Dr Mark Symes

Professor John Wilson

The committee wishes to thank all the people who contributed to this report and appreciate their giving of their valuable time.

We wish also to acknowledge the professional role of Dorothy Illing in preparing this report.

EXECUTIVE SUMMARY

Modern engineering practice lies at the interface between science and technology, and a growing range of other disciplines. It underpins human health and well-being, the global economy, and environmental health. Many, if not all, of the United Nations' Sustainable Development Goals depend on the work of engineers. It is embedded in almost every industry and every aspect of our personal lives. It is a critical, if sometimes invisible, enabler.

But seismic shifts are occurring in the role of the professional engineer, and the education system must respond. The impetus for change is being driven by the expressed needs of industry in response to the rapid advances in technology, the changing global landscape, and society's expectations.

The Australian Council of Engineering Deans has responded with a national review of engineering education. Over a two-year period, it built the evidence and developed a roadmap for significant change to the way universities respond to this new paradigm.

The last review of engineering education in Australia was conducted in 2008. Another review is not only timely but is given strong impetus by the COVID-induced events of 2020, which are already having a major impact on universities and the profile of industry. The year 2035 has been chosen as the horizon for this work as it represents generational turnover in formal education: commencing school students of 2018 will graduate from university in 2035.

The study centres on professional engineering, while acknowledging the complementary roles of professional engineers, engineering technologists, associates, technicians and tradespeople. It focuses on engineering practice and education in Australia, but also critiques best practice and emerging models of engineering education in overseas institutions.

In 2019 about 122,000 engineering students were enrolled in 35 public universities offering engineering programs in Australia. Some 50,000 of those were studying professional engineering degrees. Until 2020 the growth areas were in international enrolments, particularly in postgraduate programs; domestic enrolments have been static for the past five years. This pipeline of supply is insufficient to meet Australia's needs in a new environment where we cannot rely on international supply. Overall, 17% of Australian students were women, ranging from 11% in electrical and mechanical engineering to 45% in biomedical engineering.

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. While our engineering education system has served the country well in the past, it must change from now if it is to meet future expectations and needs.

EXECUTIVE SUMMARY

THE MAJOR FINDINGS ARE:

- Australia needs to ensure that it produces sufficient engineering graduates to meet the needs of the nation without being overly reliant on skilled migration
- Insufficient women are attracted to engineering, which represents an ongoing massive loss of potential talent for the profession and the nation. The low proportion of Aboriginal and Torres Strait Islander students must also be addressed
- Industry wants to see a re-balancing of the theory-practice components of professional engineering education, with a greater emphasis on practice, including the human dimensions of engineering
- Potential students are motivated to solve “real-world” problems and want to see that engineering practice addresses societal needs
- The diversity of engineering career options and opportunities needs to be better promoted in the school system to achieve the pipeline of engineers required to achieve the goals of the nation
- Exemplars of global best practice in curriculum and pedagogy are easily available for all engineering schools, regardless of the scale of their operation. These curriculum methods have a greater emphasis on practice and have delivered the curriculum in non-traditional ways, with a mix of on-campus and in-placement methods
- The Australian engineering academic workforce has demonstrated a willingness and capability to change education practice, particularly over the past year, demonstrated by the rapid shift to online education in March 2020

> “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.”

CALLS TO ACTION

The Australian Council of Engineering Deans developed these Calls to Action in response to the review findings.

AUSTRALIAN COUNCIL OF ENGINEERING DEANS

- Seek support from government and industry to enact and drive change
- Develop an on-going evaluation framework which will track progress of the implementation of this report to ensure the required changes are delivered
- Develop a national framework for ongoing Continuing Professional Development (CPD) for engineering academics

SCHOOLS OF ENGINEERING

- Implement adapted curriculum exemplars as appropriate to their individual circumstances. Resources from government and/or industry, to implement change, should:
  - be directed to collaborations between engineering schools
  - have clear and detailed plans for dissemination and sharing of the methods used and other resources generated
- Review and revise as appropriate appointment and promotion criteria for academic staff to give greater weight to:
  - re-balancing the emphases of performance in teaching and research to give more weight to teaching development, sustained innovation, and classroom performance
  - activities that are conducted with or in industry in a similar manner to that acknowledged within some health and creative arts disciplines
  - implementing industry engagement in all degree programs that lead to professional engineering qualifications
  - continuing professional development activities in curriculum and pedagogy innovation. (see also Engineers Australia Charted Engineering Status).
- Conduct a scoping project to identify opportunities for classifying academic staff participation in the development of professional practice learning environments as suitable activities of scholarship under Principles 1 & 2 of Part A of the Higher Education Standards Framework (Threshold Standards) 2015
- Provide greater opportunity for industry-based engineering personnel to participate in engineering education. These opportunities might be modelled on practices already implemented in the health and creative arts disciplines, including the concepts of engineering practitioners as part of the staffing profile of Schools of Engineering. The online opportunities to achieve this outcome have expanded and been demonstrated through the past year's experiences of working from home.
- Provide greater opportunities for academic staff and students to participate in industrial projects conducted within industry itself. Again, the potential of online participation has opened more ways by which this can be achieved.

INDUSTRY

- Champion the changes in curriculum outlined in this report as necessary and appropriate
- Assist in bringing more "real-world" experiences to the education of professional engineers by:
  - providing examples of, and increased opportunities for, students to participate in engineering work through work-integrated learning and other means
  - encouraging flows of academic and industry staff between the industry and academe
  - rewarding industry engineering staff who participate in such activities.

The online experience of the past year has provided greater ease of achieving this outcome.

- Provide funding and other resources for coalitions of engineering schools to implement a greater emphasis of engineering practice, including human dimensions of engineering.

CALLS TO ACTION

GOVERNMENT

- Fund greater industry engagement in engineering education. The funding will facilitate:
  - industry personnel to spend time in academe to co-teach/run projects/mentor staff and students
  - academic staff to spend time in industry to acquaint themselves with modern engineering practice
  - development and dissemination of models by which students can gain academic credit for time spent in industry, working on industry projects.
- Fund curriculum and pedagogy projects that implement adapted-as-appropriate exemplars identified in this project. Only fund projects that:
  - have collaborations between engineering schools which commit to sharing and disseminating findings with other engineering schools
  - have senior academic leadership
  - have teams that involve the profession external to universities

ENGINEERS AUSTRALIA

- Ensure that identified professional engineering attributes identified by this study are incorporated into any future reviews of the Profession's competency standards
- Further demonstrate through benchmarking and exemplars how innovative and diverse program structures can be accredited within the existing or modified accreditation criteria
- Develop resources to communicate to engineering students and industry, the meaning, process and implications of accreditation, including Provisional Accreditation, for an engineering program
- Review and revise as appropriate the criteria for Charted Professional Engineering status for academic staff to include:
  - CPD activities related to engineering curriculum and pedagogy practice that enhance industry engagement in engineering education.
  - time spent in industry over the past three years working on industrial problems.

SCHOOLS OF ENGINEERING / ENGINEERS AUSTRALIA / ATSE

- Enhance the promotion of engineering as a career by engaging in activities that balance the focus in STEM school activities that include how the 'E' in STEM can be differentiated.
- Ensure that the marketing messages to potential students are strongly aligned with the marketing report.
- Ensure the diversity of engineering career options and opportunities are better communicated in schools to achieve the pipeline of engineers needed to achieve the goals of the nation.
- Engage in activities and design curriculum that increase female and Aboriginal and Torres Strait Islander participation in engineering.
- Engage in activities to increase the number of students undertaking engineering studies to ensure that Australia has an adequate number of engineers to meet its future needs.

ENGINEERING TODAY

Engineers and engineering are indispensable contributors to Australian prosperity and health. Engineering services are embodied in almost every good or service consumed, used or traded by Australians, now and in the future. Engineers are the enablers of productivity growth because they convert "brilliant ideas" into new commercial products, processes and services.

Engineering plays a pivotal role in supporting national economies around the world and in driving economic growth. In 2016 Australia ranked 7th in a global study that used data from 99 countries to gauge the value of engineering and its role in economic development. The study published by the Royal Academy of Engineers found a strong link between a nation's engineering strength and economic development, including its GDP. Moreover, for every additional person employed in an engineering activity, the creation of 1.74 additional jobs was projected.

Many services not previously associated with engineering underpin our economy today. The stereotypes of traditional engineering roles and sectors still exist and 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, if not all, of the United Nations 17 Sustainable Development Goals depend on the work of engineers.

Analysis by Engineers Australia shows that between 2006 and 2016 (the last national census date) the engineering labour force in Australia grew by 65% from 200,000 to almost 330,000. While there was general expansion of skilled workers during that period, the growth in engineers was proportionally larger. Much of that growth was due to migration, which has since declined. At 2.9%, qualified engineers remain a small component of Australia's workforce overall - and much lower than most developed economies - yet a critical part of its economic growth. Further, the number of women enrolled in engineering in Australia is low.

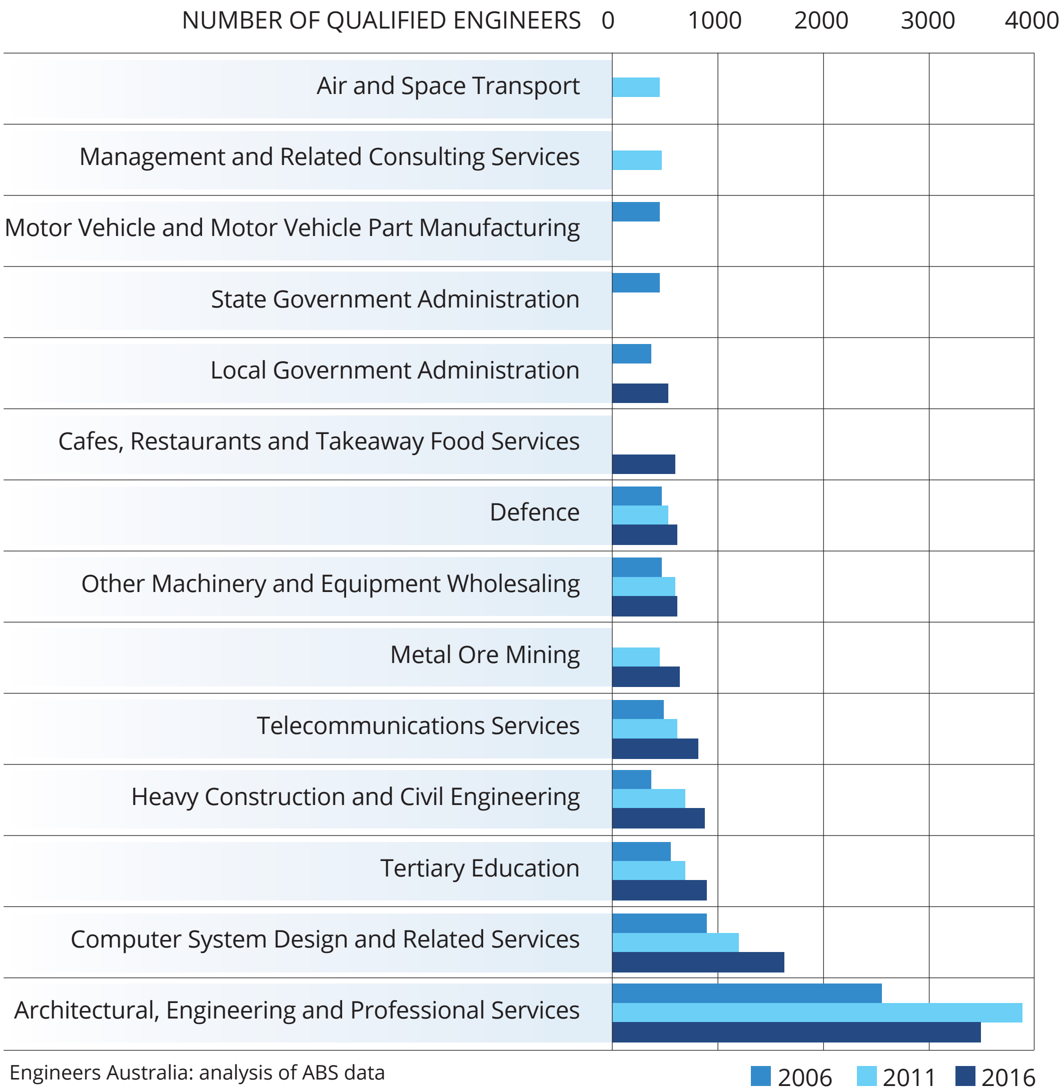
Engineers are also employed in a wide range of skilled work not classified by the Australian Bureau of Statistics and/or ANZSCO categories as engineering occupations. A growing number of graduates are working in Small-Medium Enterprises (SMEs) and technology-intensive start-ups. According to the Global Start-up Ecosystem Report 2018, both experience and formal education are important for entrepreneurs in technology start-ups. These growth sectors are part of the Third Wave of the Internet which will focus on technology-driven developments in real world and specific industries.

Rapidly expanding sectors include advanced manufacturing and robotics, agricultural technologies and new food (Agtech), blockchain and artificial intelligence, software development, big data and analytics, financial services technologies (Fintech), and Australia's mining technology services (Mintech).

The top industries of employment for engineers are:

- Professional, scientific and technical services
- Manufacturing
- Construction
- Public administration and safety
- Transport, postal and warehousing
- Computer systems design
- Mining

The Top Sectors of Employment of Engineers



Engineers Australia: analysis of ABS data

The case for change

Today engineering encompasses a broader range than ever before of areas of practice, specialisations, and interfaces with other disciplines, professions and society. These trends will continue, but at a faster rate. Technical skills and expertise in new technologies will continue to be expected, but engineering will become increasingly diverse, complex and multi-disciplinary.

While there is agreement on the broader trends, the review reveals conflicting views on the future expectations and requirements around the role of engineering disciplines, and specialisation versus breadth of education programs.

In Australia, engineering is generally considered to be based around four traditional areas of practice: civil, chemical, electrical and mechanical 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, nanomaterials, and renewable energy engineering have also emerged. ▶

But just as engineering continues to become more multi-disciplinary, so will the demand for graduates with broader skills in areas such as emotional intelligence, interpersonal skills, big picture thinking, and systems and integration. Systems engineering, for example, adopts an interdisciplinary approach that transcends individual disciplines, optimising the design, analysis and management of complex systems and projects that are becoming more prevalent in today's society.

Addressing the shortage of female engineers in the profession - a reflection of the whole STEM pipeline in the school system - will help address these broader skill dimensions. The gender issue and the STEM pipeline in the school system is considered of fundamental importance to arrest an ongoing loss of talent for the profession and the nation. So too is achieving a diverse student population that more accurately reflects Australian society.

Expectations around trust and social licence to operate will increase; engineers will be expected to apply environmental stewardship, engage more with stakeholders (interpret and translate), and to recognise the human impact of their work. Engineering will involve more collaborations and interactions across a growing range of constituencies. At the same time digital tools will be pervasive and will enable more creative work.

The use of artificial intelligence, the gig economy, data analysis of large data sets and the internet of things have the potential to profoundly influence all professional work over the next 20 years. The global COVID-19 pandemic will continue to accelerate the rate of change.

So, what will these changes mean for engineering education?

During this review, consistent messages emerged about the need for Australian engineering education 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.

Consideration also needs 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'. There will need to be more use of open-ended problems, problem finding as well as problem solving, and stronger engagement with industry and community embedded in engineering programs. The range and scope of programs will need to be more diverse. Curriculum pathways will need to attract and retain more diverse student cohorts. Graduates will need to have high levels of technical knowledge and skills as well as emotional intelligence and interpersonal skills.

PERCEPTIONS OF ENGINEERING

Perceptions of engineering vary widely, with some people viewing it through traditional fields and others attracted by a unique specialisation.

Engineering now has the potential to embrace many other fields and specialisations and move beyond its promotion via traditional core disciplines.

But to achieve this expansion and to keep pace with the demand of rapidly-evolving fields, perceptions must change. The needs and expectations of future students across all disciplines, including engineering, will be crucial. In a fast changing 21st century workplace, students will need clear and accurate information about their choices. A concerted communications and marketing effort therefore should underpin any strategy for change.

The review looked at distinctions and interpretations of engineering across different audience segments and how these impact on perceptions and positioning. Focus groups comprised year 11 and 12 students, first and second-year university students, VET students and graduates, mature age students, graduates, teachers, school career counsellors, and industry and employers in metropolitan and regional areas.

Many secondary school students associate engineering with large-scale projects such as infrastructure development, construction and production while others see it around more niche applications.

Many students are steered into engineering because they have high entrance scores or have performed well in technical subjects at school. They are also influenced by factors such as school visits and open days, or where their “mentor teacher” studied, and tend to only become aware of different employment options and industries once they are well into their degree. There is also confusion around whether specialist streams are associated with engineering or science. In essence, they are often not giving enough consideration to the diversity of engineering options now available. It is therefore important that accurate perceptions and awareness of engineering are built from an early age.

The challenges include addressing the reasons behind attrition and deferrals and how students “fall” into a course or discipline because they were steered or advised that way, were attracted by the “spin” of a program or they based their decision around other mitigating factors such as location. For future students, it is their ability to absorb and filter information that still drives much of their decision making.

Schools have an important role to fulfil in this regard, but for most career advisors and teachers, it is a major challenge keeping up to date with new and emerging engineering opportunities in a world of driverless vehicles, smart spaces, artificial intelligence, facial recognition, cyber forensics, hypersonics and medical devices.

Over the past decade, the promotion of STEM in schools has increased greatly to try and address the drop in students studying the physical science subjects. Although STEM has been promoted widely, the ‘E’ representing engineering in STEM, has remained relatively silent and needs to be amplified to increase the attractiveness of the engineering profession for school leavers of both genders.

> In summary, expected graduate outcomes of the future will be delivered by programs that focus more on practice, address real world complexity, and integrate the development of technical and non-technical competencies to provide real-world learning.

CURRICULUM CHANGE AND PEDAGOGY

In Australia 35 public universities and several private colleges provide professional engineering degree programs. Together they offer 269 Bachelor of Engineering (Honours) programs and 121 entry-to-practice Master of Engineering programs. The scale of student intakes ranges from less than 40 in smaller universities to more than 1000 in large metropolitan universities. While the structure and content of degrees vary, most domestic students complete a Bachelor of Engineering (Honours) and most international students are enrolled in master's programs.

As universities seek to meet the demands of the engineering profession, the major challenges will be in implementing change that addresses and retains the diversity across the sector, that is possible to scale up, and that has sufficient resources to deliver the desired outcomes.

To gauge how these programs might respond to necessary change, the review explored the existing landscape in Australia, and new and emerging models considered best practice overseas. A survey of engineering academics in Australia found a number of common themes around their perceptions of the elements that made up a strong "future oriented" engineering program. Among them were strong relationships and increased collaborations across industry and the community, systematic use of student-centred active learning (including project-based learning), and the availability of enabling people, processes, systems, and resources. A recurring theme across international and domestic engineering educators was the critical role of industry in preparing today's engineers.

In summary, expected graduate outcomes of the future will be delivered by programs that focus more on practice, address real world complexity, and integrate the development of technical and non-technical competencies to provide real-world learning.

The review looked at exemplar engineering programs in the United States, the United Kingdom, Singapore, Canada and Denmark. Among the distinctive features cited across each of these programs were an embedded project-based learning model (Aalborg University, Denmark), specific modules to improve empathic communication in professional skills development (University of Georgia), and a multidisciplinary design focussed approach (Singapore University of Technology and Design).

Olin College of Engineering in the US makes use of experiential learning and hands-on engineering throughout the entire program, which adopts an interdisciplinary, project-based approach combining entrepreneurship, liberal arts and traditional engineering subjects and design. The College is highly selective, has a low student-staff ratio and significant engagement between undergraduate project teams with industry and the local community. But it is seen as resource intensive and would be difficult to scale up to Australian engineering schools.

By contrast the University of Waterloo in Canada runs a large-scale co-operative program involving more than 7000 paid work placements a year across most of its undergraduate degrees. Its co-op program has been running for more than 60 years and is the largest in the world, with more than 23,000 students enrolled across 120 different programs with links to more than 7100 employers in 60 countries.

Australian engineering programs have typically been structured within a discipline base. However, in recent years, new degree programs have emerged that focus on specialisations in emerging and converging disciplines such as aerospace systems, biomedical, environmental, mechatronics, resources, and renewable energy engineering.

The curriculum review identified perceived barriers to change in Australia. They included the cost of scaling up for large cohorts, especially in practice-based education; limited access to industry partners and lack of availability of work placements; limited availability of qualified teaching staff with significant industrial practice; programs that target specific student cohorts rather than looking to a diverse student intake; resistance to change; organisational structures and disciplinary silos; and accreditation of programs that challenge traditional models.

ENGINEERING CHANGE

The review concludes that no single best-practice model for future engineering education exists, with no one-size-fits-all model that can be prescribed. However, there are substantial commonly-shared features of programs that can facilitate industrial linkages and which can be implemented at scale. The opportunities and barriers will be defined by the identity and circumstances of each university. Further diversification of program models and approaches, however, should be encouraged.

Even if it begins now, achieving curriculum change to meet the 2035 target will take years. However, the higher education sector's coordinated response to the COVID-19 pandemic is evidence of a collective national capability to respond and adapt to rapidly changing circumstances. There is now an opportunity for engineering educators to build on this momentum and pursue further innovation.

Some fundamental developments for this to occur involve the need to:

- Engage students more with contemporary professional engineering practice
- Broaden the national range of programs and graduate outcomes
- Review approaches to staffing models and develop staff expertise in teaching and learning and industrial practice
- Deploy adequate numbers of teaching staff to enable different program models to succeed
- Revise higher education funding models that allow cross-campus collaborations
- Seek funding from industry and government to provide the resources to support stronger student engagement with professional engineering practice
- Share good practice and build alliances

THE ENGINEERING ACADEMIC WORKFORCE

Any meaningful change to engineering education will require a strong academic workforce with the capabilities to deliver the desired graduate outcomes through both curriculum and pedagogic approaches that challenge traditional perceptions of a professional engineering degree. As stated in earlier sections of this report, a key factor in curriculum change will be balancing technical knowledge and skills with an increased focus on emotional intelligence and interpersonal skills. The curriculum change must also demonstrate the role of engineering in solving complex societal problems.

Historically, change in engineering education has tended to be incremental. Among the barriers to rapid change are the serious issues of scale and workforce education capabilities faced by large institutions. However, the externally imposed threat of COVID-19, and the subsequent response by universities, including the switch to emergency remote teaching, reveal a buy-in to e-learning that could be leveraged by engineering leaders to initiate a long-term and sustainable renewal of their programs. During this period academics have demonstrated the flexibility and willingness to implement transformative changes in the way they work and in their approaches to teaching and delivering future graduate capabilities.

To help understand the academic readiness or appetite for major change in teaching, the review of engineering education included closer investigation of the engineering educator workforce and attitudes to change by conducting a capabilities survey among teaching staff across all Schools of Engineering.

The seven categories of academic teaching capability identified as being required to deliver future graduate capabilities are:

- Change in teaching practice
- Integrating real-world situations in teaching
- Using digital technologies to model engineering problems
- Increasing industry collaboration
- Integrating human/social dimensions within technical contexts
- Using e-Learning
- Professional development as an engineer educator.

The survey was conducted across 36 faculties from research-intensive universities, other capital-city universities and regional universities. About 80% of responses were from those in rank-and-file academic roles (Level A to Level E).

In general, 78% of academics agreed quite strongly with the importance of substantial change and in the importance of investing more time and effort into the identified methods for achieving future graduate capabilities.

The strongest agreement was in relation to the importance of investing in e-learning (90%) and its role, followed closely by "integrating real-world issues" in teaching (87%) and "collaboration with industry" (82%). Most had a high degree of confidence that they could deliver future graduate capabilities.

But the biggest point of disagreement (80%) was their levels of confidence in relation to integrating "human and social issues" with technical knowledge in their teaching – a key factor identified in this report's previous discussion about the balance between technical skills and knowledge, and broader skills in degree programs. Lack of available time and lack of expertise were the main reasons.

Academics were also asked to identify what they considered as the most important barriers to innovating in their teaching role: time taken away from research (35%) followed by lack of available funding (26%).

The survey tested the proposition that engineering academics were comfortable with the term “transformational change” by examining their attitudes to the pace of change as well as to risk and innovation. The strongest support was for incremental change. While there was a perception that taking risks was important for innovation to occur and for academics to put forward innovative ideas, they did not believe it was always strongly supported by leadership.

CONCLUSION

The review of engineering represents the culmination of a two-year investigation into the evolving nature of professional engineering work and the consequent changes required to equip engineering graduates with appropriate knowledge, skills, and attributes for this new work environment. In particular, it heeds the views of industry, the employers of tomorrow. It is imperative that academia, industry, government and professional societies now work together to implement the changes set out in this report.

ACED
AUSTRALIAN COUNCIL
OF ENGINEERING DEANS