Engineering Futures 2035
Engineering Education Programs, Priorities & Pedagogies

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Executive Summary

The 2019 scoping study ‘Engineering Futures 2035’ commissioned by the Australian Council of Engineering Deans (ACED) investigated drivers of change, the anticipated nature of future professional engineering work, and engineering education programs that will be needed to produce fit-for-purpose graduates. Engineers of the future will require greater abilities to find and define problems before finding solutions. Both problem definition and solution will require a deeper ability to communicate and empathise with a broader range of stakeholders than has been required in the past. A greater focus on the human dimensions of engineering work and increasing complexity is also anticipated. Further details of the anticipated changes in the nature of professional engineering work and the capabilities that will be expected of future engineering graduates are provided in Section 1.

The purpose of this report is to follow up on the ACED scoping study recommendation number 2 by presenting a critique of applicable developments in engineering education, referencing national and international best practice, and emerging educational models within the higher education sector. This includes identifying exemplary engineering education programs, program models, curriculum contexts and pedagogies that have the potential to support the delivery of the T-shaped engineering graduate and the greater breadth of graduate outcomes that will be required in future. Given the large engineering student numbers at many Australian universities, scalability, and possible barriers to widespread implementation of desirable changes are of particular interest.

Consultation with national and international engineering educators and scholars collected views on program architectures, curriculum and pedagogies that will be instrumental in delivering on future graduate expectations. A national survey of leaders of Australian engineering education programs identifies programs of interest, distinctive features, measures of success, and possible barriers to more widespread implementation. Australian and international exemplars were investigated. Responses were received from 20 Australian engineering universities that are representative of the range encompassed by Australia’s 35 engineering universities. Engineering educators outside Australia were also asked for their views on horizon scanning of global best practice, innovative and ground-breaking programs from around the world and educators involved in future oriented initiatives. As with the national survey responses from international contacts were analysed to extract key themes. Details of the review methodology are provided in Section 2.

An overview of Australia’s current professional engineering education landscape, including its size, a brief summary of recent indicators of employer, graduate and student satisfaction is presented together with a summary of the range of program models in Section 3. The 4-year Bachelor of Engineering (Honours) is the entry-to-practice program completed by the majority of domestic students. However, international students are in the majority in Master level entry-to practice programs. Co-operative education programs, double degrees and vertically integrated Bachelor/ Master programs take longer than 4 years to complete.

A brief update on literature focussing on how research into professional engineering practice may inform the design of engineering education programs is provided in Section 4.1.1. Section 4.1.2 presents an overview of recent reviews of developments and challenges in world leading engineering education programs, program structures and pedagogies.

A wide range of exemplar programs was cited in the survey responses. These varied from: small cohort programs with a practice focussed approach and significant components of work integrated learning to large scale co-operative education programs; programs employing practice courses using various forms of project-based learning, including large scale deployments; and programs emphasising the sociotechnical contexts and human impacts of engineering work. Brief descriptions of the national and international exemplars cited in the survey responses are reported in sections 4.2 and 4.3 respectively. The scale of implementation of the exemplar programs ranges from small (50 or fewer commencing students per year) to large (more than 1,000 commencing students per year).

Analysis of the survey responses and cited exemplar programs reveals strong common themes on desirable characteristics. These include:

- distinctive program level philosophies

- strong program level frameworks for engagement with industry including placements for work integrated learning and/or input to practice based courses
- systematic use of student-centred active learning, including project-based learning throughout the program, beginning in the first year and incorporating community and industry-based/sourced projects
- collaboration with partner organisations from industry and the community
- use of human centred and empathic design projects, on-line simulations, competitions and roles plays
- employing a range of authentic assessments including those that evaluate deployment of multiple, coordinated competencies typical of professional practice
- the availability of enabling people, processes, systems and resources.

In summary future expected graduate outcomes will be delivered by programs that focus on practice, addressing real world complexity, and integrating the development of technical and generic competencies to provide authentic learning.

Section 5 identifies potential opportunities in the Australian professional engineering education landscape based on cited international exemplars and potentially desirable developments. Whilst Australia has several co-operative engineering education and work based learning programs these account for a relatively small proportion of the graduates. Ensuring more programs that focus on significant student engagement with professional practice is a potential opportunity. Can Australian engineering education programs engage with industry to provide student engagement with practice on a scale that is comparable with that the co-operative engineering education program placements organised by Canada's University of Waterloo? Is there also an opportunity to develop new programs which focus more on multidisciplinary, entrepreneurial, innovative engineering applications and engineering design, such as those at Singapore University of Technology and Design? The introduction of such programs would result in a broader, more diverse national range of programs and program outcomes. The role of double degrees in which engineering is coupled with a second non-engineering in delivering broader graduate outcomes also merits further consideration. Further national diversification of program models and approaches is possible.

Following the demise of the Commonwealth Government's Office of Learning and Teaching, the lack of a national grants scheme supporting higher education initiatives and development has severely restricted collaborative educational innovation. Although ACED provides limited funding for small projects, this is unable to match the scale and range of educational work needed, and deliver the number and level of achievements that flowed from the various government funded teaching and learning grants schemes.

Section 6 reports on perceived barriers to implementation of desirable changes including: the lack of access to industry, money and resources needed to scale up practice-based education and project based learning for large cohorts; the need for augmentation of the educator workforce; academic resistance to change; constraints imposed by organisational structure, and risks to accreditation associated with educational innovation aimed at producing the T-shaped engineer. Perceived accreditation risks need to be addressed in conjunction with Engineers Australia.

The opportunities and barriers to change will be defined by the identity and circumstance of each university. The importance of regional and smaller institutions and their particular needs must be considered, alongside those of large metropolitan universities.

Section 7 discusses various opportunities and develops recommendations for future action. If engineering education is to produce a much broader and more diverse range of graduate outcomes and embed the stronger focus on professional practice that is expected by industry then it is vital that stronger industry - university interactions be developed. The higher education sector's response to the COVID-19 pandemic is evidence of a collective national capability for responsiveness and adaptation to rapidly changing circumstances. There is now an opportunity for engineering educators to build on this momentum, to pursue further changes needed to educate engineers for the future.

Section 8 provides a summary of the recommendations that are developed in Section 7. These are:

R1: Engineering education providers review and revise professional engineering education programs to embed a stronger focus on student engagement with contemporary engineering practice and its sociotechnical contexts.

R2: Engineering education providers review the exemplars profiled in this report and the Male and King 2014 report 'Best Practice Guidelines for Effective Industry Engagement in Australian Engineering Degrees' that identify the learning and assessment activities that engage students with professional practice and show this can be done in different ways and at scale.

No single, unique model will suit all providers, and a blending of models to suit individual provider circumstances that leads to national diversity in delivering on R1 is encouraged.

R3: Engineering education providers act creatively to consolidate the professional and career benefits of existing double degree programs and proposed new engineering education programs that deliver significant broadening learning outcomes. Opportunities for broadening of program outcomes in existing programs should also be considered. This may involve structural changes to programs. Perceived accreditation risks be managed in cooperation with Engineers Australia.

R4: Engineering education providers deploy adequate numbers of teaching staff with appropriate experience and expertise to enable R1 whether this be through greater use of practice-based pedagogies, or project-based learning, or work integrated learning or multi-disciplinary projects.

Augmentation of the academic workforce with the capability to deliver a stronger focus on practice and broadening outcomes has been consistent theme and is the subject of a separate tranche of work and report. See Reidsema et al. (2021).

R5: Funding from industry and government be sought to provide the resources to support the embedding in engineering education programs of a stronger focus on student engagement with professional engineering practice. An industry- university- government partnership model is envisaged.

R6: Engineering education providers cooperate to build the network and alliances needed to effect the changes required to deliver on the preceding recommendations.

National leadership of a deliberative process, collective ownership, and oversight of change management is needed.

R7: Work on the preceding recommendations begins now. Major cultural shifts are involved in making the recommended changes. Even with coordinated and determined effort the transition from the present to the Engineering Futures of 2035 will take many years.

While the preceding recommendations speak directly to the education provider their realisation must engage a broader range of stakeholders and actions on associated issues. This is addressed in the combined Engineering Futures 2035 Final Report. The combined report brings together the three tranches of work on; perceptions and promotion of engineering (Lawrence, 2020), engineering education programs and pedagogies (this report), and the engineering educator workforce (Reidsema et al. 2021), and presents the resulting calls for action.

Contents

1. Introduction

Engineering educators around the world are being challenged by the impact of rapid advances in a range of technologies, increasing globalisation, changes in work, changing societal expectations and evolving human needs on the changing nature of professional engineering work and the implications for education programs. The Australian Council of Engineering Deans (ACED) has embarked on a major review of the knowledge, skills and attributes that will be required of graduate professional engineers in the future. Anticipated key skills, attributes and knowledge have been identified and reported in the ACED Scoping Study Report (Crosthwaite, 2019). Engineers of the future will require greater abilities to find and define problems before creating solutions. Problem definition and solution will require a deeper ability to communicate and empathise with a broader range of stakeholders than what has been appreciated in the past. A greater focus on the human dimensions of engineering work and increasing complexity is also anticipated. Figure 1 summarises many of the changes and contexts that have been identified in the scoping study as characterising the work and expectations of future professional engineers. A predicted increase in the diversity of professional engineering work and expectations of graduates will necessitate a greater diversity of educational outcomes, programs and pathways that are capable of attracting and retaining a more diverse cohort of students.

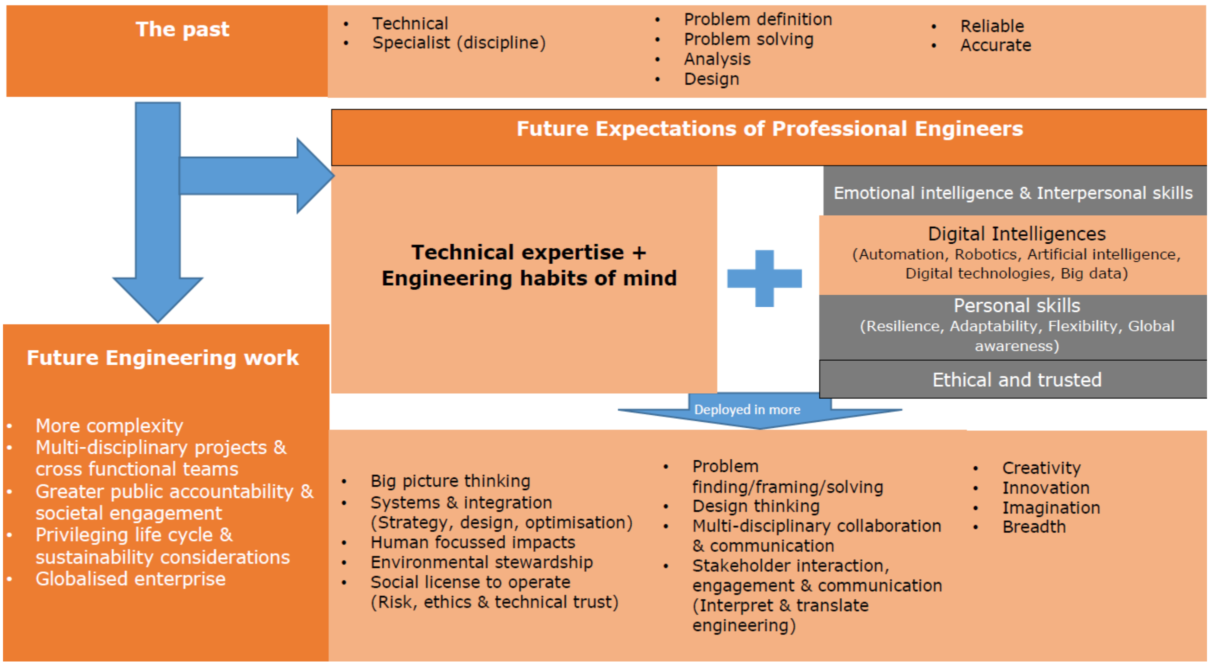

Figure 1 Anticipated futures for professional engineering work

The scoping study also identified the following key messages for change in engineering education.

1. Technical skills and expertise will continue to be expected although the role of engineering disciplines was contested. However, T-shaped outcomes will be increasingly valued.
2. 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.
3. Diversifying programs and pathways could include greater emphasis on the role of double degrees and the introduction of new engineering program models such as a ‘liberal arts degree’ with a problem finding/solving and design focus, mathematics and science foundations, and the development of engineering thinking, and judgment while fostering the capacity for lifelong learning.

4. 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. The impact of education providers' organisational structure and culture on effecting such changes will need careful consideration.
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 to adapt to the broadening requirements of engineering education.

The purpose of this report is to follow up on the ACED scoping study recommendation number 2 by presenting a critique of applicable developments in engineering education, referencing national and international best practice, and emerging educational models within the higher education sector.

This report reviews models that have been cited by engineering educators around the world as having the potential to enable engineering education to meet the more extended range of learning targets and to increase graduate diversity. These include, practice-based education and work integrated learning (WIL), programs that adopt a systems approach to curriculum design, program models that enable working across traditional discipline-oriented silos, human focussed programs, imagining engineering as a new liberal arts degree and the role of engineering double degrees and micro credentials. Perceived barriers to more widespread adoption and scaleup of exemplars are also explored.

Pedagogies such as problem and project-based learning (PBL), work integrated learning, and curriculum contexts and learning environments are also considered, including evidence of their impact and perceived barriers to more widespread adoption.

A summary of the current range of professional engineering education program models currently in use in Australia is provided as a baseline.

The report's focus is on professional engineering programs that would be considered at the Washington Accord level.

The terminology used in this report is programs e.g. the Bachelor of Engineering (Honours) comprised of courses e.g. thermodynamics.

2. Methodology

An overview of Australia's current professional engineering education landscape, including its size, a brief summary of recent indicators of employer, graduate and student satisfaction along with a desktop review of the range of program models in use is provided in Section 3.

A brief update on the literature focussing on how research into professional engineering practice may inform the design of engineering education programs; the recent review by Graham in 2018 of world leading engineering education programs, and other recent work on future directions in engineering education is summarised in Section 4.1.

Consultation with national and international engineering educators and scholars collected their views on program architectures, curriculum and pedagogies that are seen as instrumental in delivering on future graduate expectations. The consultation included surveying Engineering Associate Deans (education) in the 35 Australian universities that deliver engineering programs. The Associate Deans and colleagues were asked to respond to the following questions:

> *Nominate an education program, or cluster of courses, or course within an engineering education program (outside their own institution) that exemplifies delivery of one or more learning outcomes and professional competencies that have been identified specifically as future expectations of graduate professional engineers in the Engineering Futures 2035 project report.*
>
> *Identify the measures of success/impact that justify the above nomination.*
>
> *Identify the distinctive, enabling features of this program e.g. curriculum, pedagogy, learning environment, other.*
>
> *Identify the barriers, if any, to more widespread implementation, at scale, of this program.*

Exemplars from Australasia and other countries were requested. The Associate Deans were also asked to nominate others *'individual or group doing inspirational work and/or world leading best practice in engineering education innovation and development'* who might provide useful insights into this review. Follow up with selected contacts was undertaken to provide additional information on exemplars.

Views on opportunities that might arise in a post COVID-19 engineering education landscape were also canvassed.

A representative range of universities, large and small, metropolitan and regional, and from every state and territory responded to the survey. Survey responses were received from universities aligned with the following networks: Group of Eight (Go8 - 7 responses), Australian Technology Network (ATN - 2), Innovative Research Universities (IRU - 2), Regional Universities Network (RUN - 2) and 7 from non-aligned universities. The 57% of universities who responded to the survey account for 67% of the engineering graduates for the year 2018 (ACED, February 2020).

Engineering educators outside Australia were also asked for their views on horizon scanning of global best practice, innovative and ground-breaking programs from around the world and others who may be able to help identify future oriented initiatives. As with the national survey responses from international contacts were analysed to extract key themes. The list of Australian universities and educators who provided input into the survey and follow up consultation can be found in Appendix 1

Analysis of the 20 Australian survey responses reveals strong common themes on desirable characteristics of engineering education programs of the future. Brief descriptions of the exemplars are reported in sections 4.2 and 4.3.

Section 5 identifies gaps and potential opportunities in the Australian engineering landscape relative to the cited international exemplars and potentially desirable developments.

Perceived barriers to more widespread and large-scale implementation are also identified and discussed in Section 6.

Section 7 concludes with a summary of the key themes emerging from analysis of the exemplars and the development of recommendations for future action.

Relevant quotes from survey participants and other sources are included in Sections 4.2 to 7 *'in italics'.*

Recommendations are listed in Section 8.

3. Australia's current engineering education landscape

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 have been particularly attractive to international students.

3.1 Size

There are currently 35 public universities and several private colleges providing professional engineering degree programs in Australia. Data from the ACED Factsheet (September 2020) reproduced in Table 1 below shows that there are currently 33 providers offering 269 Bachelor of Engineering (Honours) programs and 21 providers offering 121 entry-to-practice (i.e. eligible for accreditation with Engineers Australia) Master of Engineering programs. A number of these providers operate offshore campuses that also offer engineering degrees.

The scale of engineering education programs offered by these providers ranges from student intakes of less than 40 (Charles Sturt University) to more than 1,000 at large metropolitan universities. (ACED, February 2020)

Table 1: Engineering degree programs offered by Australian providers in 2020

Award and type	Number of ACED providers**	Number of programs
Master (advanced/technical) Master (engineering managem't) *Master (entry-to-practice)	25 22 21	160 34 121
*Bach of Engineering (Hons)	33	269
*Bachelor of Technology	9	30
*Associate Degree/Adv Diploma	5	25

*eligible for EA accreditation
**ACED numbers do not include private providers.

Graduations and commencements by domestic and international students in the coursework Master and Bachelor (Honours) award categories, for 2017 to 2019, as reported in the ACED September 2020 Factsheet are shown in Tables 2 and 3 respectively. Domestic graduates and students outnumber international numbers in the Bachelor (Honours) programs (≈2:1), whereas the international to domestic ratios in the Master programs are reversed at around 4:1.

Table 2: Engineering Bachelor, Bachelor (Honours) and Coursework Master Graduations 2017 - 2019

award level	2017		2018		2019	
	Domestic	International	Domestic	International	Domestic	International
Coursework Masters	1,590	4,765	1,601	6,473	1,477	7,184
Bachelor / Bachelor (Honours)	7,741	4,301	8,285	4,692	7,724	4,852
Total	9,331	9,066	9,896	11,165	9,201	12,036

Table 3: Engineering Bachelor, Bachelor (Honours) and Coursework Master Commencements 2017 - 2019

award level	2017		2018		2019	
	Domestic	International	Domestic	International	Domestic	International
Coursework Masters	1,931	8,101	1,671	9,634	1,646	9,237
Bachelor / Bachelor (Honours)	13,672	7,482	14,238	7,447	14,284	6,987
Total	15,603	15,583	15,909	17,081	15,930	16,124

3.2 Employer, Graduate and Student Satisfaction

Analysis of engineering student and graduate satisfaction is summarised from the February 2020 ACED report as follows.

> *'The 2019 national survey of undergraduate students reported engineering students to be more satisfied than students of all fields in learner engagement (66% vs. 60%), but less satisfied in skills development (78% vs. 81%), teaching quality (75% vs. 81%), student support (70% vs. 74%), learning resources (83% vs. 84%) and overall quality of the learning experience (73% vs. 78%).*
>
> *The 2019 graduate outcomes survey reported that most engineering bachelor graduates were satisfied overall (74.4% vs. 80.1% for all fields) and in generic skills (83.8% vs. 82.4%), but fewer than half reported satisfaction for good teaching (49.4% vs. 63.7%).*
>
> *These figures do not change much from year to year.'*

Low levels of engineering graduate satisfaction of good teaching are a long-standing concern.

However, in the 2019 Quality Indicators of Learning and Teaching (QILT) survey of employers the highest overall satisfaction was accorded to Engineering at 89.9 per cent. Employers of

Engineering graduates also rated them as being above average on all five of the graduate domains surveyed:

- Foundation skills – general literacy, numeracy and communication skills and the ability to investigate and integrate knowledge.
- Adaptive skills – the ability to adapt and apply skills/ knowledge and work independently.
- Collaborative skills – teamwork and interpersonal skills.
- Technical skills – application of professional and technical knowledge and standards.
- Employability skills – ability to perform and innovate in the workplace.

There are apparent contradictions between these ratings (from direct supervisors) with others from industry that express less satisfaction, especially on the employability subscale.

3.3 Program models

Until 2008 the usual entry to professional engineering practice pathway was via completion of a 4-year embedded Honours Bachelor of Engineering degree. Many of these programs comprised a broad based first year that exposed students to an "Introduction to Engineering" (usually a project-based design or design, build, test course), studies in mathematics, and the physical, chemical and engineering sciences underpinning a broad range of engineering disciplines. Flexibility to choose or change a previously nominated engineering discipline and specialisation after completion of the first year was a feature of many providers especially those offering a large range of engineering specialisations. Most accredited engineering degree programs in Australia nominate an engineering discipline on the degree testamur (Engineers Australia, October 2020).

Within the 4-year programs there could be found some variation in emphasis across different university providers – for instance in engineering depth/specialisation vs breadth vs professional practice. There were also some variations including cooperative education programs that offered additional Work Integrated Learning (WIL) components that usually extended program durations beyond 4 years.

The last decade has seen further diversification mostly involving longer program durations. There has been a large increase in the number of universities offering accredited Master degrees as entry-to-practice programs: these are most popular with international students as can be seen in the latest ACED Factsheet (ACED, September 2020).

There has also been a large increase in the number of domestic students undertaking double degrees with some universities reporting around half or more of domestic engineering students being enrolled in and graduating from double degrees. National data for 2019 domestic engineering graduates indicates that 39% completed a program having a duration greater than 4 years. This would include co-operative education programs, double degrees and may also include the vertically integrated Bachelor/Master degree programs. Co-operative education programs contribute less than 10% of the domestic graduates and may be as low as 400 per year. (King (2020), personal communication).

The current diversity of programs can be described in terms of varying emphasis on breadth, technical depth, integration and practice dimensions.

The following schematic (Figure 2) represents the current range of engineering education programs models.

It can be argued that breadth is being delivered via double degrees in which engineering is combined with degree studies in other areas such as arts, business management, commerce, design, laws, and project management. These double degrees are usually completed in 5 or more years via parallel and independent sequences of studies from both degrees. The absence of any cross-linking of the studies from the two degrees means that the breadth is not formally contextualized with reference to or reflection on engineering practice. Anecdotal evidence suggests that graduates of double degree programs find graduate outcomes from both degrees useful in professional engineering practice.

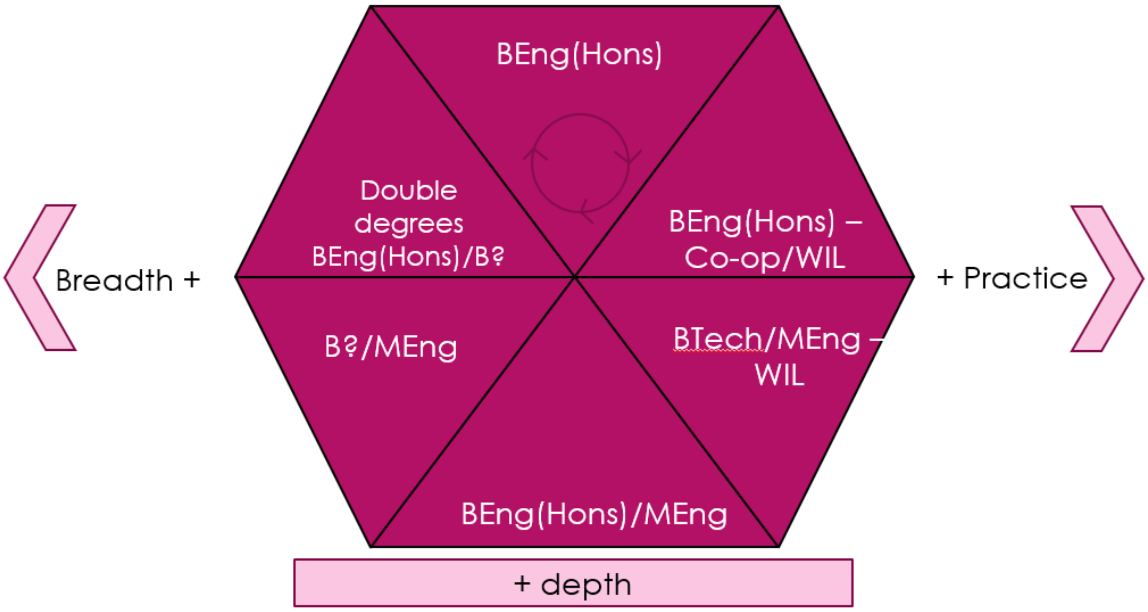

Figure 2: Australian engineering education program models

A broad-based Bachelor degree, usually in science, followed by postgraduate engineering studies is another "double degree" option: this was implemented by the University of Melbourne which discontinued its conventional 4-year Bachelor of Engineering (Honours) in 2008. The University of Western Australia also provides a 3-year Bachelor followed by a Master degree as their program for entry to professional practice.

Technical depth is a feature of 5 year vertically integrated Bachelor/Master programs such as those offered at the University of New South Wales, and the University of Queensland. Technical depth is also associated with double Bachelor Engineering (Honours)/Bachelor degrees in closely aligned engineering disciplines, sciences, mathematics and technology: such combinations are available in many universities.

Integration/systems engineering approaches albeit in a designated disciplinary context is a distinctive feature of the Australian National University (ANU) engineering programs.

A strong focus on work integrated learning via the interleaving of formal study and exposure to practice via industry work placements is a feature of the co-op style programs of the University of Technology Sydney which offers a Bachelor of Engineering (Honours)/Diploma in Professional Engineering Practice, Swinburne University of Technology's Bachelor of Engineering (Honours) (Professional), Central Queensland University, and the new work-based learning Bachelor of Technology/Master of Civil Engineering dual degree program at Charles Sturt University.

4. What should the future look like?

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 drivers for change and anticipated impacts are explored in detail in the scoping study report (Crosthwaite (2019)). 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 that have been identified. The following sections are a snapshot review of recent literature from areas informing potential development and actions.

4.1 What does literature say?

4.1.1 The connections between professional engineering practice and education

A study by Male et al (2010) which surveyed 300 engineers with five to 20 years of experience since graduation from an engineering degree of at least four years identified 11 generic engineering competency factors required by engineers graduating in Australia. These are ranked in order of decreasing importance as: communication; working in diverse teams; self-management; professionalism; creativity/problem-solving; management/leadership; engineering business; practical engineering; innovation; contextual responsibilities; and applying technical theory. Male references the need for teaching and assessments other than traditional lectures, tutorials and laboratory sessions to develop such competencies (Cameron 2009) using pedagogies and learning environments, such as problem and project-based learning.

Male also points out that the required competencies in engineering business and innovation are not explicitly listed in the current graduate attributes listed by Australia's professional accrediting body for professional engineering programs, Engineers Australia. (EA, November 2019). This has implications for engineering educators and Engineers Australia.

Passow and Passow (2017) investigated the relative importance of various generic engineering competencies. This work used the same definition for generic engineering competencies proposed by Male (2010) i.e. being important for professional engineering practice across different engineering disciplines and work contexts. They established a diverse evidence base of 52 studies that gathered information from 16,603 participants and 36,100 job postings. They found that:

> *'engineering work is typically project based' and therefore the 'required competencies are tied to the life cycle of the product, process or system'.*
>
> *'In a project context technical competence is inseparably intertwined with effective collaboration'*

with coordination, social interaction and communication being important as practising *'engineers spend more than half of their work day communicating'* and with more time being spent in oral than written communication.

They also report that competencies required for practice are different from the required learning outcomes and graduate competencies listed by America's ABET (Accreditation Board for Engineering and Technology) and the International Engineers Alliance's (IEA) Washington Accord. Missing outcomes/competencies include: *'take initiative, think creatively, and make decisions'*. Project management and finance are also noted as being not well covered. The International Engineering Alliance and partner organisations are currently reviewing the graduate attributes for the various accords.

Not only are technical and collaborative competencies inseparable but coordination of multiple competencies to accomplish a goal is important. Whilst acknowledging that individual competencies are essential they suggest that the absence of a 'unifying portrait' means the loss of *'the most important concept, which is that in engineering practice, competencies are intertwined and coordinated.'*

A key message to engineering educators from the Passow and Passow study is that

> *'Engineering education could better coordinate competencies as in engineering practice.'*

This study concludes with three 'paradigm-shifting principles for curriculum design pertaining to coordinating competencies as in practice':

'Engineering work extends far beyond science-based tasks to activities – both technical' and social – that are critical to project success.

"Non-technical skills cannot be taught in isolation from the technical context in which they will be used."

Engineering education needs a greater connection to practice from the first day.'

The last point aligns closely with Bennett's 2016 work with Australian university leaders on employABILITY which established widespread agreement that:

'You have to stay true to the essential ingredients of the academic program, but its applications in the wider world of work seem to be something you should build on and develop and embed very early on'.

A more recent review by Mazzurco et al (2020) of 187 papers on engineering practice published in peer reviewed journals since 2000 confirmed that

'all these studies came to the same conclusions: among all the competencies that engineers need, professional competencies (e.g. team-work, communication skills) are as important, if not even more important, than technical competencies, and engineers tend to have not developed professional competencies during university as much as required for practice'

and

'whilst the collected literature makes it clear that professional skills are certainly as important as technical skills, the variations in relevance and importance of each skill across the spectrum of engineering practice remains poorly understood.'

Notwithstanding the highest employer satisfaction ratings given to engineering graduates in recent years (QILT 2020), Trevelyan (2019) claims that *'explicit curriculum reforms addressing graduate attributes and workplace skills have not resulted in significant employability improvements'.* He postulates the need for educators to consider the hidden curriculum including the absence from explicit engineering curricula of finance as part of greater '*curriculum gaps and infrastructures'* and practices that inhibit change along with assessment practices and priorities that contribute to *'raising resistance to reform efforts'* via

'value conflicts between education and workplaces, particularly the valuing of technical over social, marginalising the influence of finance, prioritising individual performance over socialisation and collaboration, prioritising written communication and hiding social and emotional influences. The often implied, sometimes explicit association between collaboration and cheating in formal education could further reinforce this influence'

'Research has shown that a deep understanding of the contemporary work place by teaching faculty is needed for skills instruction to have an impact (Bennett 2016) and, as we have seen, this is currently not available in engineering schools.' (Cameron et al. 2011)

4.1.2 Current and future directions in engineering education

Graham's (2018) global review of engineering education involved interviews with 178 engineering educators from around the world who identified distinctive features of current and emerging leaders in engineering education.

Good practice found in programs cited as currently world leading include

'user-centred design, technology driven entrepreneurship, active project-based learning and a focus on rigor in the engineering 'fundamentals'.'

Whereas for those seen as emerging leaders the distinctive educational features include

'work-based learning, multidisciplinary programs and a dual emphasis on engineering design and student reflection.'

Graham identifies four major challenges that are constraining future progress in engineering education as:

1. *'The alignment between government and universities in their priorities and vision for engineering education;*
2. *The challenge of delivering high-quality, student centred education to large and diverse student cohorts;*
3. *The siloed nature of many engineering schools and universities that inhibits collaboration and cross-disciplinary learning;*
4. *Faculty appointment, promotion and tenure systems that reinforce an academic culture that does not appropriately prioritize and reward teaching excellence.'*

It is noteworthy that the challenges identified in Graham's survey do not include the lack of mutual understandings between Faculty and Industry that seems to be a particular challenge for Australian engineering schools. This issue is considered by Crawley et al. (2020) in 'Universities as Engines of Economic Development' which explores practices underpinning economically productive engagement of engineering and technology faculties with stakeholders. These are illustrated with case studies including several relating to engineering education programs examined later in this report in Section 4.3 International Exemplars.

Graham's report also anticipates:

1. *'the ascendancy of engineering education programs in Asia and South America where strategic government investment in engineering education is seen as a driver of national economic growth.'*
2. *'a move towards more socially relevant and outward facing engineering curricula.'* and *'distinctive, student centred curricular experiences within an integrated and unified educational approach.'*
3. *'the emergence of a new generation of leaders in engineering education that delivers integrated student-centred curricula at scale.'*

Hadgraft and Kolmos (2020) in their recent review of current engineering education practices and future directions echo and enlarge on many of Graham's findings. They argue that addressing cross-disciplinarity, complexity, systems, human values and sustainability, requires a much more coordinated and integrated curriculum, crossing the traditional boundaries of single modules.

In their review of current and short term future good practice they reference student centred learning, most often in the form of problem based and project organised learning (PBL). There are many different forms of PBL implemented in engineering education some of which have been described by Kolmos and De Graff (2014) and analysed by Chen et al (2020). PBL can be implemented at course, cross course and program levels with projects of varying size and complexity, and focussed on a range of different outcomes. Guerra, Ulseth and Kolmos (2017) describe seven different examples from around the world of PBL in engineering education ranging from course to program to institutional level implementations.

Kolmos and De Graf (2014) provide a comprehensive discussion of the development, range and dimensions of PBL in engineering education and three underlying learning principles:

1. *'the learning process which involves working with problems organised via projects and case studies,*
2. *the social approach which covers team based learning and participant directed learning; and*
3. *the content approach which covers the selection of knowledge and skills'*

Kolmos and Holgaard (2010) also distinguish between study project/discipline projects and innovation project/problem projects which represent new knowledge creation and are real-life projects: when appropriately assessed these will drive learning that addresses the desired complexity, creativity and innovation outcomes.

Kolmos et al (2020) also propose that as

> *'a consequence of the increasing need for complex problem solving, there is a need to increase diversity in the types of project that students work on. It is not enough to let engineering students focus on parts of complex systems; they also have to capture the interconnectivity and dependencies of complex systems to address wicked problems. It is not*

enough to work with projects from within a discipline, as complex problem-solving most often calls for interdisciplinary synergy.

They present '*four ideal types of educational project categories: single discipline projects, multi-projects, interdisciplinary projects and megaprojects'* dimensioned according to:

> *'1) the scientific content and problem scoping, ranging from simple and complicated problems to complex and interdisciplinary problems; and*
>
> *2) the size and organization of the team(s) implicitly involved in project management processes on varying levels. '*

A deliberate distinction is also made by Hadragft and Kolmos (2020) between course based projects and a more program oriented approach to curriculum design and implementation that enables

> *'organising projects of various sizes and types of problems and learning outcomes. Problems can range from academic- and theoretically initiated projects to projects initiated by different societal and industry actors with more authentic problems. Most often, this is some kind of student project in collaboration with a company or a member of the broader community, or it is a project identified and formulated by students themselves'.*

Hadgraft and Kolmos also point to the importance of experiential learning or contextual practice – related learning in association with student centred learning as a growing trend that encompasses a range '*from an informant or case level where students go out to observe practices, to real collaboration and partnership where students are working on solving identified problems in the company*' to internships.

More extensive use of student-centred active learning, particularly for large classes has been enabled by educational technology. (Prince (2004) provides useful reviews of various forms of active learning and evidence of their effectiveness). For instance flipped classrooms that combine remote virtual learning with active campus-based learning can deliver content before classes which can then engage students in a classroom that *'is much more dominated by learning activities where there are facilitated activities to prepare them for assignments (Bishop and Verleger 2013; Jenkins et al.2017; Reidsema et al. 2017)'.*

Echoing Passow and Passow (2017), Hadgraft and Kolmos also point to Professional Competencies and the '*growing importance of the integrated learning of professional competencies.*' Tracking and evidencing personalised learning including outcomes from participation in collaborative activities '*will increase and become a new, emerging trend. Portfolios will play a key role in this process, helping students to articulate their learning to themselves, their academic mentors, and to future employers at a job interview.'*

Kolmos and Hadgraft predict a future that sees a continuation of:

> *'an overarching trend, there has definitely been a move from teacher-driven to much more of a student-driven learning environment and an emerging trend is a tendency to start developing curricula at a system level, which involves coordinating all the curriculum elements'.* and
>
> *'new models of learning have shifted from single modules to whole-of curriculum models, from single disciplines (the simple and the complicated, with technological knowledge and skills taught in single modules) to integrated curricula based on complicated and sometimes complex problems.'*

Continuation along these trajectories will help address points 2 and 3 of the four major challenges identified in Graham's global study (2018) that are seen as constraining future progress in engineering education.

The following sections look at particular examples of programs from Australia and elsewhere that have been identified by survey participants as having the potential to deliver on future expectations of graduates.

4.2 Australian Exemplars

The results in this section are derived primarily from Australian survey responses noting the caveats made in the following responses.

'I am sure there are great examples of subjects and subject clusters in most of our programs, but we don't have many whole courses redesigned with these attributes in mind. I would think that we are all evolving in these directions and that this is the only way we will be able to change.'

'Having profile and being known is not a measure of success of course'

Notwithstanding these concerns a number of consistent and convergent themes emerged around programs aiming to be to industry integrated and focussed on practice, project based and multidisciplinary.

4.2.1 Exposure to professional practice

This is a consistent, recurring theme emerging from the Australian survey data. Exemplars of Australian programs cited by survey respondents can be categorised according to the extent and nature of exposure to and engagement with professional practice.

Sixty percent of the survey responses cited the (now discontinued) engineering program at the Swinburne University of Technology (SUT) Engineering Practice Academy and Charles Sturt University (CSU) for their strong program level focus on exposure to professional practice (practice-based education), addressing real world complexity, and the integrated development of technical and generic competencies as authentic learning experiences. These programs involve students learning via placements in authentic professional practice environments and could be considered to be an engineering version of the apprenticeship model that characterises medical education programs.

The SUT Engineering Practice Academy (EPA) operated as an engineering consultancy with students learning and working on real projects sourced from industry and the community in six-week sprints (terms). Practice Academy associates (students) enrolled in a Bachelor of Engineering Practice (Honours) (BEPH) program that was structured around 5 aptitude domains of: thinking; work; process; self; and (engineering) discipline with each domain being divided into a number of graduate 'capabilities'. In all a total of 15 different capabilities represented what graduates should be able to do in practice as shown in Figure 3. Capabilities were broken down into streams which were further divided into and delivered as micro-credentials (provided on-line) which supported the associates' engagement with projects and provided structure to evidence associates' practice. The micro-credentials were modules of work that covered both professional and theoretical skills needed to complete a project, or aligned with the broader capabilities associates needed to develop to graduate. There were no examinations, and instead grades were based on performance in projects, completing micro-credentials and on an individual development project. Student projects were sourced from industry providing both authentic industry-based issues, contexts and complexities, as well as meaningful outcomes for clients and students. They were supported by structured reflective practice to ensure that students also learned from failure, gaining valuable experience.

The Bachelor of Engineering Practice (Honours) was delivered within a purpose-built space designed to promote open collaboration and external engagement, providing a mix of formal and informal learning and working spaces within the Engineering Practice Academy.

The Bachelor of Engineering Practice (Honours) (before it was discontinued) was about to seek provisional accreditation from Engineers Australia as a Systems Engineering outcome. This reflected both the expressed needs from industry stakeholders involved in the design of the program and the broader EPA, as well as differentiating the program from the existing (and continuing) discipline-based engineering programs at Swinburne.

Figure 3: Bachelor of Engineering Practice (Honours) curriculum domains (Mann et al. 2020)

A detailed description of the practice-based education framework that underpinned the Swinburne Practice Academy program and its implementation is given in Mann et al (2020).

The Faculty of Science, Engineering and Technology at SUT advises that:

> *'The key learnings from two years of delivering the BEPH were that the projects need to be scoped by a dedicated workforce, in the EPA this was done by Engineers in Residence. The projects were then delivered to the students by academics, working in tandem with the Engineers in Residence, and in some cases industry professionals.*
>
> *There is a need for scaffolded support for students, who work in groups to deliver on industry based projects. The modularised credential part of the curriculum needs both academic and industry evaluation. Experience showed that when credentials were directly linked to specific projects there was a higher level of student engagement.'*
>
> *'The EPA has also highlighted the need for a more consistent model of interaction with industry throughout degree programs, not just in the final year. This has been verified through an industry survey that shows that many of our current partners have a greater capacity and willingness for engagement with students at different levels in their degree program.'*

The Faculty intends to transfer learnings from their experience with the EPA into a pedagogical model underpinning an embedded STEM spine in all of the faculty's undergraduate degrees.

> *'The STEM Spine comprises of a common set of learning outcomes, a knowledge framework, a pedagogical approach, and an industry engagement capability framework.'*

The CSU program is a 5.5. year joint Bachelor of Technology/Master of Civil Systems Engineering. This program comprises 18 months of on campus immersive project-based design challenges followed by a sequence of 4 paid 12-month work placements that are supported by on-line delivery of technical engineering content (via an online topic tree) enabling self-directed experiential and just in time learning as well as feeding into project portfolios. Further details of the Charles Sturt program can be found in Lindsay and Morgan (2016) and Graham's 2018 'The global state of the art in engineering education' which recognised and reported in detail on the CSU program as one of four exemplary case studies of world leading engineering education programs.

Both the SUT BEPH and CSU programs were new, designed from a blank slate, and involve significant industry partnerships that are integral to both the program design and delivery. Both had/have small (< 50 - 100) commencing student enrolments per year.

Survey respondents saw scale up of such programs for delivery to the large student cohorts found in many Australian engineering schools as problematic citing difficulties associated with engaging sufficiently and appropriately with industry to develop and deliver such high quality, immersive learning experiences to large numbers of students. The difficulty of accessing industry support for and engagement in such programs was cited by many, including both large metropolitan and smaller regional universities.

Practice Courses: The strategic use of an embedded program spine of 4 or more 'practice' courses that span all years of more conventional 4-year BE(Hons) programs, can be delivered to large cohorts (400 – 1,000+), and are deployed across all engineering disciplines was also cited as exemplary. Although such practice courses are typically delivered to engineering students from all disciplines, they sometimes employ a range of different discipline-oriented projects. The spine of 'practice courses' at the University of Newcastle (Cuskelly and McBride 2017) is one example. Macquarie University's Bachelor of Engineering (Honours) program also has a similar practice course spine (Town et al., 2017). Problem and project-based learning is a feature of these courses which aim to integrate theory and practice and technical with professional competencies (Tse and Di Bona, 2019).

Graham (2018) identified the delivery of high-quality student-centred education to large and diverse cohorts as one of four big challenges for the future of engineering education. While the impacts of these relatively new practice course frameworks are still to be evaluated, establishing a practice backbone may be a viable consideration for some programs. The proposed development and implementation of the SUT STEM spine appears to be a similar framework.

The importance of including first year 'practice' courses/experiences that tap into creativity and begin the fostering of coordinated professional competencies in an engineering context was also recognised. Most universities offer at least one first year course that is intended to introduce students to the nature of engineering and start building professional capabilities and identity. These courses are often built around team projects requiring the students to "design, build, and test" a prototype capable of meeting specified client needs. These courses are, in some universities, delivered to very large cohorts i.e. 1,000 or more students using an array of well scaffolded learning activities and resources. They are often considered to be iconic first year learning experiences (Cuskelly and McBride, 2017) and *'cognitive apprenticeship experiences'* that *'begin the development of students into practising engineers'* (Reidsema et al. 2016). First year engineering courses at Monash University, The University of Queensland, and studio courses at UTS were mentioned as exemplars in the survey responses. The appropriate use of educational technology is essential in effectively delivering such courses to large cohorts.

4.2.2 University Outreach

University outreach to industry and the community is also considered significant via flagship events such as the University of Adelaide's annual public expo of engineering student's project work. The University of Adelaide provided the following information.

> *'Ingenuity is an annual flagship event for the Faculty of Engineering, Computer and Mathematical Sciences (ECMS), and serves as a platform for students to professionally present their work to a wide range of audiences. Ingenuity 2019 showcased 308 student projects presented by 678 student exhibitors from within our engineering, computer science and mathematical sciences disciplines. The event brought over 5,000 attendees through the doors, which included: industry representatives (300+), primary and high school students (3500), international partner representatives, family, friends, students, staff and the general public. Filling three combined halls of the Adelaide Convention Centre covering a space totalling 5,630sqm, Ingenuity is the largest event of its kind in South Australia.*
>
> *For final year engineering students, Ingenuity is a showcase of their honours projects and forms a part of their assessment.*
>
> *In 2020, the Faculty of ECMS are using a virtual platform to showcase over 250 student projects in a safe and interactive way, offering local, national and global communities an opportunity to connect…. Complementing the virtual platform are a suite of high school outreach activities, as well as a smaller scale face to face expo to enable engagement with some of the faculty's key external partners.'*

4.2.3 Problem/Project Based Learning

PBL is explicitly cited in 30% of the national survey responses as a distinguishing feature of exemplary programs. Australian programs mentioned in the survey responses in the context of using these approaches, in addition to the SUT and CSU programs described previously, include Deakin University with their work on Project Oriented Design Based Learning (Chandrasekaran et al, 2013, 2015, and Long et al. 2016)), RMIT University where PBL is used in civil, chemical and environmental engineering programs (Parthasarathy and Jollands, 2009), Central Queensland University where PBL is also used in various forms in its engineering programs, and the University of Queensland's project centred curriculum in chemical engineering in which:

> *'Projects are designed to be substantial pieces of original work that simulate real engineering practice using topical tasks and problems sourced from industry and research. They encompass real scenarios that incorporate diverse factors, views and perceptions and therefore provide opportunities to develop both technical and generic skills in communication, teamwork and independent learning in a professional practice context.'* (Crosthwaite et al, 2006)

While there are examples of PBL projects that bring students from different engineering disciplines together, the involvement of students from other non-engineering and engineering technology disciplines in engineering project courses in Australia is rare although not unknown. Examples have been reported by Kavanagh and Cokely (2011), Lynch et al. (2019) and Prpic and Hadgraft, (2011).

While PBL is often used as a means of connecting students with professional practice in industry and contemporary issues it can also be used to connect students with engineering research. Studios such as those offered at UTS (Summer Studios) and the University of New South Wales (ChallENG) are specifically designed to engage students in engineering research projects. PBL projects can also be extended across multiple courses across multiple years. Undergraduate students at UNSW can engage with long term multidisciplinary research projects via a sequence of three consecutive course modules in the Vertically Integrated Projects pillar of the ChallENG program. These courses earn academic elective credit.

4.2.4 New programs based around emerging needs and humanitarian engineering

Programs focussing on a number of 'future facing' disciplines such as smart manufacturing, renewable energy engineering, mechatronics, and biomedical engineering were also cited as being important. These are offered at a number of Australian engineering universities at both undergraduate and postgraduate levels.

> *'Education programs need to shift towards smart manufacturing as well as development of health care and assistive technologies as the Australian engineering sector is unlikely to return to the mining and mineral/material processing setup. Engineering education must produce graduates who can become part of the rapidly evolving high-tech engineering industry.'*

There were also several mentions of the new minor in humanitarian engineering and the Australian National University's (ANU). The minor comprises 4 courses accounting for 12.5% of the study completed towards the Bachelor of Engineering (honours) program. https://programsandcourses.anu.edu.au/minor/huen-min Distinctive features are cited in the survey responses as strongly engaged partners & collaborators including a deep partnership with Engineers Without Borders (EWB), excellent staffing and having teaching strongly linked to research.

EWB Australia is a not for profit organisation that has partnered with many universities and engineering faculties in particular through their use in first year engineering programs of the EWB Challenge. https://www.ewb.org.au/project/ewb-challenge/ The Challenge provides an opportunity for students to work on real problems for real communities. The Challenge has a *'strong and distinctive focus on the development of graduate attributes related to social, cross cultural and ethical responsibilities in a global context'* (Jolly 2014). Immersive in country Humanitarian Design Summits are also available https://www.ewb.org.au/project/design-summit/ as are research projects for later year students https://www.ewb.org.au/project/research-program/ .

Jolly's 2014 national evaluation of the impact of the use of EWB Challenge in a number of Australasian engineering programs at different universities concluded that:

> *'use of the EWB Challenge provides good opportunities for pursuing the desired changes to learning outcomes for engineering students' but 'other kinds of project could be equally successful as long as some basic principles are followed. Achieving best outcomes, regardless of the type of project chosen, is more likely where there is:*
>
> *Commitment to and clear and detailed communication of rationale for the intervention and its methods,*
>
> *Well-aligned course and assessment design that does not rely on content alone to structure learning outcomes,*
>
> *Attention to outcomes rather than outputs,*
>
> *Coherence in teaching approaches across the teaching team and in line with stated objectives.'*

4.2.5 Key Features and measures of success

Key learning activities and experiences embodied in the preceding exemplars are:

1. strong program level frameworks for engagement with industry that include the provision of work placements for work integrated learning and input to practice based courses.
2. systematic use of project-based learning throughout the program beginning in the first year and incorporating industry-based and/or industry-sourced projects including those that can be delivered to large (400 – 1,000+) cohorts. Ideally these learning experiences possess at least one of the following attributes:
    a. realistic, multidisciplinary, and collaborative
    b. require innovation, creative input and decision-making
    c. focus on complexity including the United Nations Sustainable Development Goals
    d. may have an international dimension
    e. make effective use of relevant educational technologies to deliver content just in time, and
    f. use assessment paradigms that consider project processes as well as end products: they do not use traditional end of semester written examinations.
3. use of human centred and empathic design projects, on-line simulations, competitions and roles plays such as those enabled by the award-winning on-line simulation Mekong e Sim developed jointly by Professor Holger Maier from the University of Adelaide and the University of Technology Sydney.
4. collaboration with partner organisations from industry and the community including not for profit humanitarian organisations such as Engineers Without Borders (EWB).

Distinctive program level features include: an approach that treats students as trainee/junior engineers rather than engineering students, embedding extensive industry collaboration and engagement into the curriculum, and student work that draws on current real world issues. These approaches often refer to student engineers rather engineering students, this is seen as an important distinction.

Program approaches that are responsive to and aligned with student needs and industry needs is also seen as relevant.

Making greater and more effective use of educational technologies to enable more flexible delivery modes including remote on line and blended learning is also seen as a significant development arising from the COVID-19 pandemic.

Survey responses stated that COVID-19 has

> *'forced many academics to change their teaching practice for the better'* and *'focussed minds on what is (and isn't) important to do on campus'.* It has *'challenged the reliance on traditional didactic education'. 'People have "discovered" things that should stick even if we return to Face to Face teaching. They have realised that some things are better online and have been forced to question the role of Face to Face Teaching and Learning'.*

> *'The speed with which Engineering institutions successfully transitioned to online delivery must be commended. It is important that lessons learned from this experience are directed to develop strategies that will take engineering education away from the traditional L&T methods, to benefit everyone involved.'*

> *'Tutorials can be run online, sometimes with much better engagement. What we really need to work on are laboratories and design projects with hands on activities. Perhaps our new model will be all lectures and tutorials online, leaving the bulk of learning to project-based labs and design projects that can be done face-to-face, on campus and/or within a business.'*

> *The move to more on-line education could also encompass 'greater use of on-line simulations and remote access laboratories'.*

There is now an opportunity for rethinking what the best value add elements of campus-based education will be as a result of the shift to greater use of on-line teaching, blended learning, and flipped class room pedagogies.

> *'we might see a swing from bricks and mortar campus' to the more online ones for a group of students, and/or the Bricks and Mortar campus's will need to more strongly support a dual mode of education.'*

Some survey responses suggest this '*may offer access to a more diverse student cohort*.'

Learning environments associated with these approaches are industry placements including paid work placements and specialised teaching spaces such as collaborative spaces, *'with engineers in residence to assist learning like you would in a large engineering firm as a junior engineer'*. Access to maker spaces is also seen as important.

As reported by Graham 2018, there appears to widespread agreement amongst engineering educators that evaluation of the impact of an engineering education program on student learning and graduate outcomes is generally not done well: Aalborg University in Denmark is a notable exception. As stated in one of the survey responses: *'Having profile and being known is not a measure of success of course'.* Survey responses cited measures of impact and indicators of success as reputation (domestic and international recognition), industry support, job ready graduates and their employment, levels of student engagement, continuing professional development of academics in teaching and learning, and program longevity.

4.3 International Exemplars

Themes consistent with those of the Australian examples cited such as exposure to practice including WIL, project-based learning, curriculum-based collaborations with industry and community partners are also evident in the nominated international programs. However, a new theme also emerges from multidisciplinary design-focussed programs that operate outside Australia. The following list is ordered with formal curriculum-based program models reported first, followed by discipline specific program nominations, a voluntary course-based professional skills set of modules, and finally voluntary extracurricular programs, some of which also contain courses that can be taken for academic credit.

4.3.1 Olin College of Engineering (USA)

Olin is well known and highly regarded as an exemplar for the future of engineering education. It is a niche program with a global reputation for excellence and successful graduates. Olin 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 as initially described by Somerville et al (2005) and more recently in Crawley et al (2020) *'Students in all majors take a common set of core classes. The core includes modeling and simulation, measurement and control, human-centered design, and an* *introductory entrepreneurship course, where students start developing an entrepreneurial mindset and learn tools essential for realizing sustainable change. Later semesters offer more opportunities for diverging paths, while also intermingling students across levels and majors. The culmination is a student-directed final year capstone.'*

Creativity, interdisciplinary collaboration and communication are valued and '*process outcomes are emphasized rather than comprehensive content coverage*'.

> *'Olin does not have distinct academic departments. Instead, faculty from engineering, mathematics, science, arts, humanities, social science, and entrepreneurship are brought together in a single academic unit. Faculty members are on performance-based renewable multiyear contracts'* (Crawley et al. 2020)

Olin College enjoys a very low student-to-staff ratio, and significant engagement and collaboration of undergraduate research project teams not only with industry but also the local community. Programs are offered in mechanical engineering, electrical engineering and in an engineering program which provides the opportunity for the student to design an area of concentrated study such as bioengineering, computing, design and robotics. Total commencing enrolments and graduations in Spring 2020 were 159 and 90 respectively. https://www.olin.edu/about/accreditation/

The Olin model is seen as being resource intensive and not readily scaled up to the large cohorts educated in the larger Australian and other engineering schools. Barriers to widespread implementation are cited as cost, a program design that is seem as not readily catering to a more diverse student cohort, and academics' resistance. Olin had the advantage of being able *'to build everything from scratch'*. It is

> *'much harder to transform an existing institution where most staff have very limited knowledge or interest in pedagogy and how we teach. When we do talk about teaching it is nearly always about what we teach (content-driven). Hard to do anything really different when consensus is required. Hard to find enough leaders with enough knowledge, passion and time to drive big changes.'*

However, educational technology is seen as potentially useful in deploying elements of the Olin approach more widely e.g. using a hybrid approach, where content is delivered synchronously online, and teams work online except when they meet face to face for hands-on activities.

4.3.2 University College London (UCL) Integrated Engineering Program (IEP) (UK)

UCL is a research-intensive university that is consistently ranked among the world's leading universities. UCL Engineering offers a range of engineering degree programs and currently enrols in the order of 1,000 students per year in its Master of Engineering degree programs. These are entry to professional engineering practice programs. The IEP operates primarily in the first two years of these programs and is built around a sequence of project-based learning modules. These are embedded in most of the university's undergraduate engineering programs. Projects emphasise design, interdisciplinarity, creativity, communication, teamwork, and the social context of engineering. Central to the IEP implementation is its common Engineering Faculty wide curriculum structure. Distinctive and enabling features are cited in the survey responses as:

> *'engineering wide leadership, and an engineering wide curriculum model in the first two years.'…'This is a rare construct. Especially at a large research-intensive university'*

Comprehensive details of the design, development and implementation of this program are available in Graham 2018. The following summary draws on the Graham report, the UCL IEP web-site https://www.ucl.ac.uk/engineering/study/undergraduate/how-we-teach and information provided by UCL's Professor John Mitchell.

The first element of the IEP curriculum is introduced in the first term of study and involves two five-week team project challenges: the first is discipline based and aims to provide insights into innovation in the chosen engineering discipline; the second is multidisciplinary and brings staff and students from different engineering disciplines together to work on a real-world project. Four hours per week are allocated for students to work on their challenge project. Although the first challenge is disciplinary based they use a common timetable, and shared learning outcomes and assessment protocols. The second element of the IEP is two Design and Professional Skills modules which are taught in the first and second year of study. These are taught for specific discipline cohorts and lead into week-long intensive (all other lectures stop) scenarios. Scenarios are team based technical design focussed projects: they are taught by departments with a total of 6 scenarios being done by students during the first two years. The first 4 scenarios are supported by discipline core modules and the Design and Professional Skills modules that are taught in four-week blocks that precede the scenario weeks. Graham (2018) reports that the scenarios are designed to become progressively more complex and open ended; and they are usually managed by a departmental teaching fellow with some support from the staff teaching the linked discipline core modules. The IEP also contains two mathematical modelling and analysis modules that are taught faculty wide. At the end of their first year students choose an IEP minor comprising three modules which can be used for either broadening into complementary disciplines or specialisation in a particular area of interest. The list of IEP minors available for Autumn 2021 is shown in Figure 4.

The final element of the IEP is 'How to Change The World (HTCW)'. This is a two week intensive multidisciplinary project that is the culmination of the eight Challenge and Scenario projects. HTCW projects are aligned with the United Nations Sustainable Development Goals and supported by industry and government. Students are divided into groups of about 100 with each group addressing a different humanitarian challenge; the students work in multidisciplinary teams of around 5 on their chosen project. These projects are led by an interdisciplinary team from the faculty. UCL describes their approach as follows:

> *'Working in facilitated workshops with industry and/or community partners, your team will plan and design an engineering solution to a socially complex real issue assigned to you. On the final day, you'll pitch to a panel of academics and external and internal (UCL) experts. In recent years, our prestigious external partners have included the UK Government Department for Transport, ARUP, Engineers without Borders UK, Motorola Solutions and Lloyds Banking Group.'* https://www.ucl.ac.uk/engineering/study/undergraduate/how-we-teach

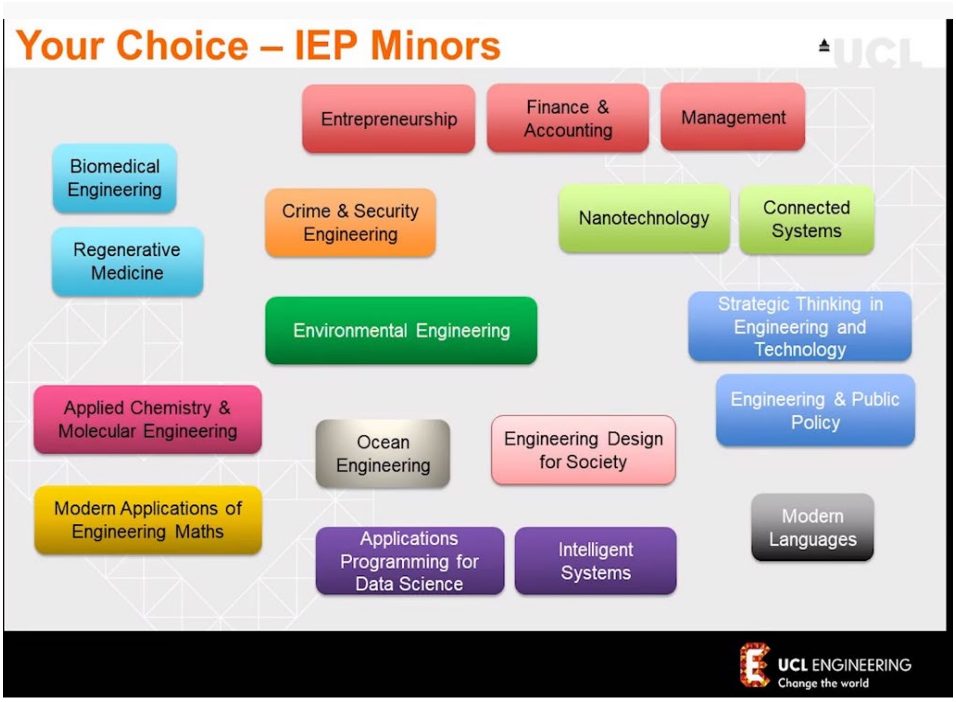

Figure 4: IEP minors at UCL Autumn 2021
https://www.youtube.com/watch?v=auy2petn3BU&feature=youtu.be

Collectively projects across the first two years emphasise design, interdisciplinarity, creativity, communication, teamwork, and the social context of engineering. Assessment focusses on project process and well as the end product.

Of particular note is the scale of this initiative's implementation which is comparable with Australia's largest engineering faculties which typically admit of the order of 1,000 new engineering undergraduates per year. Also of note is the adoption of a common teaching timetable built around short (5 week) intensives and the use of teaching fellows/specialists who manage some of the scenario projects. The IEP also engages with the UCL Centre for Engineering Education https://www.ucl.ac.uk/centre-for-engineering-education/

Three dedicated IEP appointments were made to support the program and lead the professional skills, projects, and mathematics components of the IEP. An annual budget of around £300,000 covers undergraduate and postgraduate teaching assistant salaries and project materials. While the IEP curriculum and culture is now well established, access to suitable project-oriented teaching spaces is an ongoing concern. (Mitchell (2020) personal communication)

Identifying and ensuring an ongoing supply of suitable inter-disciplinary and multi-disciplinary problems aligned with the research (and teaching) expertise of their academic staff projects was identified by Australian survey respondents as a possible concern re adoption of such a model.

4.3.3 Aalborg University's Problem/Project Based Learning (PBL)

Aalborg's PBL approach has long been recognised for excellence. It is also one of the few models for which published evidence of impact on graduate outcomes is available. For instance, Kjærsdam (2004) discusses the results of a survey of 487 Danish companies that showed superior engineering graduate outcomes from Aalborg's problem-based project learning in areas such as creative and innovative skills, and people and project management. The survey also rated the quality of engineering and technical skills of Aalborg graduates as being equivalent to those of graduates from the Technical University of Denmark (DTU), which at that time used a more traditional lecture, laboratory work and supporting project approach. In a similar vein Kolmos and Holgaard (2010) reported that in a subsequent survey Danish companies continued to rate Aalborg University as the engineering institution which is *'best in developing engineering education according to the needs of society and companies'*. (DTU has now incorporated much more project-based learning). As previously indicated in the literature review there are many different forms of PBL with the type of outcomes being delivered dependent on the particular implementation. The nature and scope of the projects, and the alignment between intended learning outcomes and assessment is crucial.

The Aalborg model is described in Crawley et al (2020) as '*A curriculum rich with projects where student teams work on authentic problems to develop professionally relevant competencies through guided reflection'*. It comprises a 50% student (team) project each semester and 3 x modules (subjects). The project is graded, and the modules are pass/fail. Assessment for the project is a 3-hour interview, usually with an 1-2 academics and an industry representative. Students present and then are interviewed, so that every student gets an individual grade. The project links together the learning outcomes from the semester's modules. Projects are expected to be obtained from industry and from the community.

Crawley et al. (2020) also reports that

> *'In parallel with the project work, students are guided by academic staff to reflect on their process competencies, most notably the ability to communicate and collaborate internally and externally with facilitators, stakeholders, and project management.'*
>
> *'Aalborg University has a new digital strategy, Knowledge for the World, with profound implications for its PBL model. The aim is to equip students to develop the digital skills required in society in which digitalization plays an ever-increasing role…..The taught courses will increasingly adopt digital modes, offerings opportunities to learn just-in-time, as the knowledge is needed in their projects..*

Survey respondents claim that both academics and students need to be trained in the skills needed to work in PBL mode.

PBL approaches being deployed at other international Universities including Rose Hulman in the USA were also mentioned in survey responses.

4.3.4 New Model Institute for Technology and Engineering (NMITE) (UK)

NMITE is a new university that, like Olin College, will teach engineering through student centred hands-on active learning and project-based learning drawing on *'real world engineering challenges* *set by real world organisations*' (NMITE, 2020). NMITE is now moving from the program design and development phase to implementation of its 3-year accelerated integrated Master of Engineering (MEng) program. The first intake of 50 'pioneer' students is planned for 2021. There will be multiple intakes in a year with the anticipated final steady state producing 250 graduates per year.

The MEng program is scheduled around students working 9 – 5 everyday over a full working week, with limited holiday breaks that simulates a real working environment. The program is built around a suite of 2-3 week toolboxes that equip students with fundamental ways of thinking, and 3.5 week engineering sprints framed around an associated challenge (i.e. a problem/project), essentially using a PBL pedagogy. Overall there are 17 different sprints each with an associated challenge. Student groups of 25 will be assigned to a dedicated studio to work on a sprint in 5 groups of 5. Studios are designed to facilitate collaboration including around collaborative work surfaces, room arrangements and technologies. Adjoining quiet spaces allow students a change of environment and pace. Instructors work with students in the studio. Students will also have access to a Factory (workshop) space when building artefacts as part of projects or challenges. There are no lecture theatres.

The program also involves 2 x 6-week projects for local community partners at the end of years 1 and 2. The final (3rd year) requires students to undertake an additional 4 advanced sprints. These are themed around big, complex issues such as health, infrastructure, energy and security. Two individual projects are also done in the final year.

Students will come into contact with a wide variety of community and industry partners from whom the challenges and projects are sourced. Community partnerships are seen as being of particular importance in the program.

A dedicated partnership team manages the NMITE relationship with community and industry and works with them to broker suitable student projects. The partnerships team is currently led by an engineer.

A program level assessment plan directs the use of a wide variety of different assessments. There are no invigilated exams. Oral assessments will be heavily used. Debates, reflections, project plans, business plans, test reports, peer reviews and built artefacts are just some of the planned assessment activities. Each sprint will use 3 different assessments: these will be a mix of individual and team assessments.

Humanities and liberal arts are integrated into the curriculum from the start: e.g. art, aesthetics, observation and rhetoric are introduced during the first year to give students exposure to working with different mindsets. For instance, the early exploration of the concept of "certainty" aims to get students comfortable with subjectivity.

Another novel element is the absence of an entry requirement for Maths or Physics A-levels, which is very unusual in the UK context. Students will be supported in maths development through the Academic Skills Centre, which has a careful mapping of concepts required throughout the programme. Time is allocated for skills development, but assessment occurs within engineering work in sprints – essentially, learners are assessed on their ability to deploy mathematic concepts and techniques in engineering contexts. Through this approach, NMITE hopes to open up the pipeline of potential future engineers and have much more diverse classrooms.

The academic work force comprises educators who are experienced in (and passionate about) student centred active learning pedagogies, and/or are from an industrial background that brings experience of engineering practice, and an understanding of professional conduct. All educators pursue a deep understanding of context, not only in their own disciplines, but also across other disciplines and in a global context including the United Nations Sustainable Development Goals. Educators will be involved in delivering each sprint multiple times in any one year as the cohorts are cycled through the sprint.

Distinctive features of this model are the intensive mode of delivery with timely content delivery integrated with challenge and project activity, the integrated inclusion of humanities, purpose built collaborative learning environments, a program level assessment plan employing many different assessment modes (but no invigilated exams), and strong student engagement with local community and industry partners via challenges and projects.

Appropriate governance is seen as instrumental in enabling this new and different model and is a potential impediment to transferability more widely.

4.3.5 University of Waterloo, Canada

Waterloo runs a large-scale co-operative (co-op) education program involving more than 7,000 paid work placements per year across most of its undergraduate degree programs. https://uwaterloo.ca/engineering/future-undergraduate-students/co-op-experience Waterloo's co-op program has been running for more than 40 years. It is the largest in the world and in 2019 had over 23,000 students enrolled across 120 different programs, with links to over 7,100 employers in 60 different countries. The program allows students to gain real world experience (up to 2 years) through a sequence of work terms that are interleaved with formal curriculum based terms. A suite of professional development courses that cover career basics such as resume writing, interview skills and critical self reflection supports the program. https://uwaterloo.ca/professional-development-program/students/which-courses-do-you-take

The program is run at the institutional level through a large department that coordinates and supports student and employer involvement in the program. The University sources and qualifies co-op placements for which students then apply via WaterlooWorks the online site run by the University. Student applications and employer preferences are ranked and matched in a process that aims to provide equal access for both parties. Ross Johnston and Richard Wikkerink from the University of Waterloo provided the following information. Just under 15% of students were placed internationally in 2017/2018 with 2/3 of these being in the USA. Operation of the program via a dedicated co-operative education department that is not tied to a single faculty is seen as instrumental in the program's quality, autonomy, and scale. The program is fully funded through co-op fees which are paid by students. https://uwaterloo.ca/co-operative-education/your-co-op-fee The co-op program fee for an engineering student would typically be CA$3,600 for the minimum of 5 work terms distributed across the engineering degree. Pre-COVID-19 work terms were typically 16 weeks; this has been reduced to a minimum of 8 weeks.

Engineering and architecture students at Waterloo are automatically entered into the co-op program in which completion of a minimum of 5 work terms is a graduation requirement. In Fall of 2019 there were 7,808 engineering students enrolled across 20 different programs. 9,460 work terms were completed by engineering students which accounted from 42% of all co-op work terms in 2019/2020. For each work term completed within Canada in 2019 engineering students earned between $8,400 and $19,200.

An Associate Dean Co-operative Education and Professional Affairs coordinates the co-op activities in the Faculty of Engineering. This includes working with faculty academics on co-op matters such as employment rates, co-op requirements, changes, issues, needs, and first work term student preparation for co-op. Regular meetings are held with department chairs, program curriculum coordinators and program and student representatives.

Work terms are assessed by the employer via an employer evaluation form consisting of the assessment of defined skills. Students also submit a work term report for some, but not all work terms (3 – 6). Reports can have a reflection format (few pages long) or technical focus (10-20 pages) or require both.

Academic staff from the relevant engineering departments are involved in assessing work term reports. As assessment of work term reports is a program responsibility a range of different approaches are used.

Waterloo also has a research institute, founded in 2002 as the Waterloo Centre for the Advancement of Co-operative Education, that is actively researching WIL and co-op education. https://uwaterloo.ca/work-learn-institute/

4.3.6 Purdue University's School of Engineering Education

This group is recognised for the scholarly research and evidence driven innovation in pedagogical approaches to engineering education and Purdue's first-year engineering program in particular. This includes students working on projects sourced from external partners and EPICS, the long-established community service project program which has been adopted by other universities around the world. The first-year engineering student cohort at Purdue is comparable in size to Australia's larger engineering faculties. The Purdue University School of Engineering Education First Year Engineering 2019 Impact Report says that in Fall 2018, 1,238 first year students engaged in design projects for external client organisations and 294 first year EPICS students worked on design projects which *'addressed human, community or environmental needs.'* First year students can also enrol in a Vertically Integrated Project (VIP) program which enables undergraduates to work in interdisciplinary teams involving research staff and students engaged in ambitious long running projects. Undergraduates may earn academic credit via VIP for up to 4 years of participation. https://engineering.purdue.edu/VIP/about

The Graham 2018 report also noted views on

> *'Purdue's 'leadership in "figuring out how you can do hands-on learning at scale" '.*

Purdue also offer programs in multidisciplinary engineering that combines several academic disciplines to focus on a particular area of interest. The Bachelor of Science in multidisciplinary engineering is ABET accredited and provides

> *'tailored engineering programs, and unique interdisciplinary experiences for undergraduate students attracted to study at the interfaces of traditional disciplines.'*

Disciplines include acoustics, theatre, lighting, visual design, engineering management and humanitarian engineering. https://engineering.purdue.edu/ENE/Academics/Undergrad/MDE/about

Purdue also offers an interdisciplinary engineering program that

> *'provides an engineering education for students who do not intend to work in engineering practice'.* https://engineering.purdue.edu/ENE/Academics/Undergrad/IDE

4.3.7 Singapore University of Technology and Design (SUTD)

SUTD is a new research-intensive university established in Singapore via a collaboration with MIT and Zhejiang University. SUTD enrolled its first undergraduate students in 2012. Like Olin, SUTD has the advantage of being a newly established, well-endowed university that started with a blank slate when designing its programs. It is unusual in that its engineering education programs are based around 4 pillars rather than traditional engineering disciplines. It offers three engineering undergraduate programs focussed on fostering multidisciplinary design capabilities via the Bachelor of Engineering which is available in three areas (pillars) of: Engineering Product Development, Engineering Systems and Design, and Information Systems Technology and Design. These three programs are accredited by Singapore's' Engineers Accreditation Board https://www.sutd.edu.sg/About-Us/Accreditation . The first year is common to all programs with all modules in the first term and two in each of terms 2 and 3 being graded on a pass/fail basis. Design and maker-based learning experiences are pervasive, occurring within courses, across courses, across academic years and in student-initiated projects (SUTD's four-dimensional big design (4-D, Big-D) framework) (Crawley et al. 2020). The University has extensive prototyping facilities available for student use. Graham (2018) reports that a graduating student will have completed between 20 and 30 substantial design projects, some of which can be revisited and extended across multiple years of the program. Another notable feature is the offering of a multidisciplinary team-based capstone design project experience that brings together students from different areas. Capstone projects must involve students from at least two different pillars (Crawley et al. 2020) and can either address real world challenges that are drawn from and supported by industry or an entrepreneurial, technology based start-up idea. Industry partners pay S$6,000 per team to participate and retain IP generated from the capstone project. https://www.sutd.edu.sg/Education/Unique-Academic-Structure/Capstone-Programme/For-Industry-Partners Humanities and social sciences along with use of digital technologies are also significant elements of the curriculum. https://www.sutd.edu.sg/Education/Unique-Academic-Structure/undergraduate-curriculum Crawley et al. (2020) report a student: faculty ratio of 11:1.

4.3.8 Singapore Republic Polytechnic

The Republic Polytechnic offers Diploma (not Washington Accord level) programs in engineering and other areas and is well known for its adoption of Problem Based Learning in the form of "one day one problem". Yew and O'Grady (2012) outlined the Republic Polytechnic approach to PBL through which *'Over the course of a week students will work on five different problems'*.

Republic Polytechnic is cited for '*its strong focus on engagement with industry, the number of external industry partners and the proportion of academic staff that are still engaged in industry*.' As stated in Yew and O'Grady (2012) the role of Singapore's Polytechnics is to *'produce practice oriented and knowledgeable middle level professionals'**. This is endorsed by the following survey comment on the Republic Polytechnic

> *'The goal is to produce graduate engineers* for industry, not potential PhD students. Facilities, curriculum and culture all reflect that focus, and they live the values by having their academics also engage via consulting and sabbatical.'*
>
> *'The mindset of practice is the key distinctive feature. The Engineer identity is developed right from day one, with the underpinning technical curriculum delivered in the service of practice.*
>
> *The porosity of the program to industry ensures that what is being taught is actually what engineers will need – there are interactions on multiple levels that allow for reciprocal information flow between multiple partners, rather than just relying on a (hopefully) representative Industry advisory committee.'*

* The Diploma programs are not accredited by the Institution of Engineers Singapore at the Washington Accord level. https://www.ies.org.sg/Accreditation/EAB10249

4.3.9 National University of Singapore (NUS)

The (NUS) Bachelor of Engineering program which admits around 1,500 new students a year is also cited for having

> *'undergone major change in the last five years, with the introduction of project-based Engineering Professionalism and Practice (EPP) modules for all students, three pathways for professional engineering, entrepreneurship and research respectively, and common units of study across all disciplines on machine learning, materials, etc. The curriculum has been re-designed to enable cross-disciplinary experience and project-based learning. New classrooms have been built with the latest multimedia technology and reconfigurable seats and tables, that encourage group discussions. University and Faculty-level management are both aligned in support of the changes, and academic staff are therefore being persuaded to support these changes as well.*
>
> *The changes are too new to have their success/impact quantified, but they aim to break down barriers between engineering disciplines, introduce project-based learning from day one, cater to students with different interests by allowing a lot of elective space, and encourages innovation and entrepreneurship. All of these are goals in line with the Engineering Future 2035 report.'*

Accreditation is perceived as a major barrier '*to the implementation of programs such as the one at NUS which create the T-shaped engineer that industry needs*'.

Generating academic staff buy-in and ownership of such change is also a significant challenge.

> *'Alongside the accreditation hurdles, there are still many academics who prefer to teach the same material in the same style for 20 years, and throw up objections to change that are based on nothing other than inertia.'*

The National University of Singapore was also identified in the Graham 2018 report as appearing in the top ten of both current and emerging leaders in engineering education with the Innovation and Design Program pathway which includes multiyear design projects, the degree's flexibility in terms of options and electives available to students https://www.eng.nus.edu.sg/undergraduate/degree-programmes/pathways/ and the commitment to global experiences *'70% of their undergraduates spend at least one semester at a university abroad'* being cited.

4.3.10 Discipline specific programs

Several discipline specific engineering programs were also cited. These included biological engineering at MIT for being future facing in terms of the new and/or growing engineering specialisations likely to be in demand.

Caltech in Pasadena California is also cited for the quality of its engineering programs and graduates in general and the Bachelor of Mechanical Engineering in particular. Caltech is a very small, privately supported institution. Undergraduates may choose from 28 majors and 13 minors from six academic divisions, three of which involve a range of engineering specialisations. Interdisciplinary programs are also available. Caltech enjoys a student to staff ratio of 3:1 and has a total undergraduate enrolment of less than 1,000 students. https://www.caltech.edu/about Caltech is academically elite with students being required to maintain a minimum Grade Point Average for program progression.

The preceding exemplars are all compulsory, curriculum-based programs. Several optional course modules and programs were also cited as exemplary. These include:

4.3.11 Professional skills modules

The University of Georgia where Walther, Sochacka and colleagues have trialled a sequence of four seventy-five minute modules to improve empathic communication as part of developing professional skills (Youngblood et al. 2019) and emotional intelligence capabilities (Walther et al. 2017). Walther et al. (2019) argue that empathy is important in a range of engineering graduate outcomes and professional practice applications, and that students *'need explicit training in empathy to offset the analytic cognitive bias of undergraduate engineering degree programs'*. Workshops involving skills development use *'role play to improve perspective-taking, empathic communication and switching between empathic and analytical modes'*. Adaptations are currently being trialled at the University of Western Australia and several other American universities (Sochacka et al. 2020).

4.3.12 Voluntary programs

MIT's New Engineering Education Transformation (NEET) https://neet.mit.edu is a 3 year extra-curricular certificate program that began in 2017 and is intended to address similar learning outcomes to those identified in the Engineering Futures 2035 scoping study report. NEET provides students with the opportunities to engage in NEET "threads" built using cross departmental/cross disciplinary project centred learning that is framed around new machines and systems. At present there are five different threads available: Advanced Material Machines; Autonomous Machines; Digital Cities; Living Machines, and Renewable Energy Machines. Each of the threads is aligned with and supported by a particular set of academic course options and requirements, many of which can contribute credit to a student's chosen major, but may also incur additional time commitments. While some threads are restricted to particular majors, any first year MIT student may apply to join a thread. Enrolment in three of the five threads is currently capped with new enrolments in the digital cities, living machines, and autonomous machines threads limited to 30 https://neet.mit.edu/threads/dc#faq_dc , 30 https://neet.mit.edu/threads/lm#faq_lm ,and 35 per year https://neet.mit.edu/threads/am#faq_am respectively.

NEET ways of thinking are listed as: '*learning to learn; making; discovering; interpersonal skills; personal skills and attitudes; creative thinking; systems thinking; critical and metacognitive thinking; analytical thinking; computational thinking; experimental and humanistic'*. https://neet.mit.edu/about#guiding_principles

Stanford University's Global Engineering Program (GEP) '*aims to enhance engineering education by providing students with an opportunity to learn about technology and engineering globally, to build professional networks and to gain real-world work experience in a culturally diverse and international environment'*. Initially founded in 2007 as an exchange program with Tsinghua University '*GEP's international programs now span several continents and encompass research, service work, internship opportunities, and academic study tours. GEP has sent hundreds of engineering students abroad and plans to continue improving the opportunities it offers future engineers to provide them with the skills and the knowledge to make decisions with a global perspective'*. https://engineering.stanford.edu/students-academics/global-engineering-programs

4.3.13 Other commentary

Follow up with international colleagues who were asked for their views also revealed other programs that are seen as leading best practice, and/or creative, bold and potentially transformative. These include:

Fulbright University Vietnam, a new liberal arts university developing an engineering program that will blend liberal arts, science and engineering. https://fulbright.edu.vn/curriculum/

Pontificia Universidad Católica de Chile which Graham (2018) reports as having a

> *'curricular focus on "building deeper relationships with industry and society" both within and beyond Chile which is reflected in many of the projects and experiences offered to students…. Entrepreneurship and innovation are also prominent'. 'The school is also investing in a range of new multidisciplinary learning spaces and maker spaces as well as a department of engineering education to provide an evidence base for it curricular development.'*

University of San Diego Integrated Engineering Program which aims to develop a broad multidisciplinary technical foundation that is supplemented by additional studies in an area of interest. https://www.sandiego.edu/engineering/programs/integrated-engineering/

Minnesota State University Mankato Iron Range Engineering (IRE) Program. IRE works closely with local industry and community in delivering the final 2 years of an engineering degree using an adaptation of Aalborg University's PBL model. Students work on authentic semester long design projects that are supported by technical learning, professional development and extensive formative assessment. Students are typically community college graduates. The program started small, but has aspirations to scale-up from 50 to 500 students (Johnson and Ulseth, 2017) and expand into a full four-year offering using a revised approach that will see students working on industry sites on industry projects. https://www.ire.minnstate.edu/

Other PBL adopters mentioned include Chalmers University which is implementing a project track, Delft's aerospace engineering which is project organised and Twente University which has transformed into a project centric mode and provides a structured program of professional development in teaching and learning for staff.

University of Washington Bachelor of Science in Human Centered Design & Engineering which is founded on *'engineering principles rooted in a broad range of disciplines to investigate the interaction of people with technology and technical development.'*
https://www.hcde.washington.edu/bs

NSF RED. The USA's National Science Foundation (NSF) grant program "Revolutionising Engineering Departments (RED)" is supporting innovation, adaptation and implementation projects and is reported to have resulted in many innovations in the USA.
https://www.nsf.gov/awardsearch/advancedSearchResult?ProgEleCode=012Y,1340&BooleanElement=Any&BooleanRef=Any&ActiveAwards=true&#results

5. Opportunities for Australian engineering education?

Australian engineering programs have typically been structured for discipline-based contexts such as Civil, Mechanical, Electrical, Mining and Chemical Engineering. Recent years have seen the development of new degree programs focussing on specialisations in emerging and converging disciplines such as Aerospace Systems, Biomedical, Environmental, Mechatronics, Resources, and Renewable Energy Engineering.

5.1 A stronger focus on engineering design

While design is a focus in many of these discipline based programs and there are also several specialised engineering design programs such as Swinburne University of Technology's Bachelor of Engineering (honours) (product design), RMIT University's 'electronic product design' and the Australian Maritime College's 'maritime design' (Engineers Australia, 2020), Australia has little in the way of multidisciplinary design-focussed engineering programs such as the undergraduate programs offered at SUTD or the transnational postgraduate Global Innovation Design and Innovation Design Engineering programs offered jointly by Imperial College London and the Royal College of Art. The SUTD program is recognised by the relevant national engineering accreditation bodies. https://www.sutd.edu.sg/About-Us/Accreditation . However, there are a number of double degree programs available in Australia in which engineering is offered in conjunction with degree studies in design including architectural design and industrial design. These include the University of Queensland's Bachelor of Engineering (Honours)/Bachelor of Design https://my.uq.edu.au/programs-courses/program.html?acad_prog=2515 , QUT's Bachelor of Design/Bachelor of Engineering Honours https://www.qut.edu.au/courses/bachelor-of-designbachelor-of-engineering-honours and The University of Sydney and Monash University which offer civil engineering combined with architectural design. https://www.sydney.edu.au/courses/courses/uc/bachelor-of-engineering-honours-civil-and-bachelor-of-design-in-architecture0.html and https://www.monash.edu/study/courses/find-a-course/2021/engineering-and-architectural-design-e3009?domestic=true

There appears to be an opportunity for Australian engineering education programs that provide a stronger emphasis on engineering design, as well as applications and professional skills

> *'we have the opportunity to change the way we teach fundamental subjects, from a focus on analysis, to a focus on design and application. This would allow the digital design tools to be introduced earlier in the curriculum. Having a project subject in every semester enables this quite naturally.*
>
> *Getting students into a design mentality earlier also helps to build the professional skills that are necessary – collaboration, communication, teamwork, creativity, ethics, sustainability, etc.'*

5.2 Strengthened broadening programs

Somewhat surprisingly double degree offerings were not recognised in the Australian survey responses as being instrumental in delivering on a broader range of graduate outcomes. It could be argued that the availability and popularity of double degrees in which engineering is combined with another non-engineering degree provides a significant breadth component through completion of studies in another area that must help deliver graduates with an ability to communicate and empathise with a broader range of stakeholders. While this is undoubtedly true for many double degree combinations, the two component programs are usually delivered as discrete sequences of study that do not include any cross-program connections. While there may be strong naturally occurring synergies between some double degree program components, the benefits of better connectivity could be considered with particular attention given to the approaches used in stand-alone engineering programs that include integrated and contextualised components from the humanities, liberal arts and social sciences. Cross program reflection and/or a joint program capstone are two possibilities that could be explored. Given the student interest in double degrees would it be worthwhile investigating possible ways to better capture and consolidate desired breadth and diversity outcomes through these programs?

Engaging other non-engineering disciplines in joint teaching in engineering programs appears to be much more difficult. Lynch et al. (2019) provide a useful overview of the issues and makes recommendations for developing interdisciplinary student projects based on recent experience at ANU. While there are several other examples of where engineering students have been engaged in interdisciplinary collaborations (Kavanagh and Cokely (2011) and Pripic and Hadgraft (2011), these initiatives can be short-lived as they are sustained only by the enthusiasm of individual staff members who champion these challenging interactions. When these staff members move on the interaction is lost.

The UTS approach adopted in the Bachelor of Creative Intelligence & Innovation which is not a stand-alone degree and is available only when taken in conjunction with another professional degree, including the Bachelor of Engineering (honours) may provide insights into potentially useful double degree synergies and connectivity. The Bachelor of Creative Intelligence & Innovation engages students from a range of disciplines in a multidisciplinary program.

5.3 Pervasive program level engagement with industry and professional practice

There are a number of Australian engineering programs that use a cooperative education model or involve completion of an internship (as distinct from the 12 weeks work experience required for graduation from many engineering programs). However, the student numbers are small relative to those of Canada's University of Waterloo where 7,800 students in the engineering faculty were enrolled in over 20 co-op programs in Fall 2019 (Johnston and Wikkerink (2020) personal communication). While it might be argued that the proximity to the USA is a critical enabler, 85% of all of the University of Waterloo's co-op work terms are completed in Canada. Canada's population is approximately 1.6 times that of Australia. Australia's UTS is well known for its cooperative engineering education program which embeds two periods of 24-week internship (leading to the award of the Bachelor of Engineering (Honours) and the Diploma of Professional Engineering Practice) completed around second year and fourth year of the five-year degree program. This program graduated around 300 students per year from 2018 to 2020 (Jarman (2021) personal communication).

Can leaders of Australian engineering education programs aspire, in conjunction with leadership by industry and support from government, to national scaling up of its cooperative education and internship offerings in engineering education?

5.4 National funding schemes supporting innovation and development in higher education.

Australia no longer has a national grants scheme that funds innovation and development in higher education. Through the now discontinued Carrick Institute/Australian Learning and Teaching Council/Office of Learning and Teaching grants, engineering educators across the country enjoyed a period of successful cross institutional collaboration and development that led to many improvements in program and curriculum design, teaching and learning quality and the student experience. Although ACED provides limited funding for small projects, this is unable to match the range of work and achievements that flowed from the various government funded teaching and learning grants schemes.

6. Identified Barriers to change?

While acknowledging the benefits of more practice-based education and project-based learning approaches, survey respondents also cited the difficulties of more widespread adoption associated with the following seven challenges. As in the previous sections direct quotes from survey responses are shown *'in italics'*.

6.1. Cost of scale up for large cohorts

Over half of survey responses identified the cost of scale up to be a significant challenge, especially in practice-based education approaches for large cohorts and/or in regions without ready access to big industry.

> *'I just don't see how these approaches scale up to the sort of numbers that most universities teach. These (approaches) take in (only) around 30 students each. They run in specialist spaces including maker spaces.'*

> *'Some innovative programs are just too expensive to run at scale, especially when you really need to do lots of marking and/or involve lots of companies in meaningful ways. It is very hard to make the numbers add up in institutions where teaching must subsidise research.'*

> *'Highly resource-intensive and unlikely to be more widely adopted by universities due to financial constraints'*

Notwithstanding the above concerns, there are a number of exemplar programs operating at large scale that employ various forms of practice-based education.

6.2 Engagement with industry

Limited access to industry partners, and the limited availability of industry/work placements are seen as significant barriers to more widespread implementation of more practice-based approaches.

> *'A well-developed ecosystem of productive industry-academia partnerships may not be easily accessible to all the current Australian providers of Engineering education. This may be particularly so for regional campuses that deliver Engineering education.'*

However, the COVID-19 induced move to online work and online education is also seen as providing opportunities to reinvent modes of industry engagement in teaching programs.

> *'Just like universities have had to shift, companies have had to shift to be more comfortable with "remote work". This may translate into increase engagement opportunities with industry as it reduces a significant logistical barrier for connecting students and staff.'*

> *'There is an opportunity for engineering educators to embed much more input from industry practitioners into the subjects they are teaching. Industry and academia have been forced to become more comfortable with the use of videoconference technology and this provides a great opportunity to enable more participation from practitioners without it being a huge time contribution as they can participate from wherever they are.'*

6.3 Academic/educator work force

Other resourcing impediments cited include: the limited availability of appropriately qualified teaching staff, and the current funding levels for teaching and learning coupled with the perceived resource intensive requirements of practice focussed programs, PBL, and integrated programs addressing broader socio-technical, multidisciplinary outcomes and professional capabilities.

> *'Broader more integrated and societal thinking and exposure to different approaches in achieving a desired level of professionalism might be better achieved if more people with different backgrounds (i.e. from industry, communities) are involved in teaching process. This would especially be the case in the areas of design, communication and stakeholder involvement.*

> *The 2035 expectations will require a major shift in how engineers are trained. To make this shift innovative teaching methods implemented by academics should be combined with*

additional input sought from the wider engineering community, who have a large stake in this initiative.'

'Project design and integration of curriculum is key and requires expertise that may be lacking in some institutions'.

'Scaling PBL is the biggest challenge, though it can be done. We have to stop thinking that teaching 300+ students can be done by one expert and several well-meaning PhD students, who are technically proficient but lack the facilitation skills to lead a PBL tutorial/workshop. We need to recruit (and train) our tutors from industry as well as from our students, both PhD and senior undergraduate and Master students.'

6.4 Diversity of intake

Some programs were seen by survey respondents as aimed primarily at a particular student cohort rather than catering for a more diverse student intake.

'It would be challenging to engage students in this program who are not in the high achiever category or are from equity groups.'

'Program was only offered to a subset of engineering students'. 'Highly resource-intensive and unlikely to be more widely adopted by universities due to financial constraints'

6.5 Resistance to change

Several respondents were also concerned about academics' resistance to the adoption of new program models, implementing new teaching approaches and resistance to cultural shifts embodied in these changes.

'engineers seeing the importance of learning stakeholder perspective taking skills and the 'soft' arts of negotiation and influence (and teamwork) early on….. There is still resistance to these kinds of pedagogies from some more traditional engineers.'

'Most barriers are the usual barriers to change: academics were taught a certain way themselves, and mostly just follow that with minor tweaks.'

'Requires staff buy in for a very different model of engineering education'

'Buy in - bringing the necessary 'cultural change''

6.6 Organisational Structures and Disciplinary silos

Organisational barriers were also identified including rigid established course and teaching structures, timetables and policies, and disciplinary 'silos' necessitating negotiation of cross disciplinary agreements for multidisciplinary initiatives.

'multidisciplinary activities seem very hard to do because of Faculty boundaries and concerns around teaching income and different accreditation requirements'

The UCL IEP is an example of a model that has successfully developed a cross faculty approach that brings various engineering disciplines together in a shared program with joint teaching and multidisciplinary projects.

6.7 Accreditation

Some respondents also pointed to concerns with accreditation.

'These approaches are so different that it's difficult for an accreditation panel, particularly when trying to get provisional accreditation, to see what the full course will deliver as course learning outcomes and graduate attributes. There has to be more flexibility in accreditation if more courses like this are to be considered.'

'Accreditation teams seem more likely to focus on the sufficiency of engineering technical content, rather than the sufficiency of complementary knowledge within the curriculum.'

7. Where to from here?

7.1 Improved responsiveness and adaptability

The universities' rapid response to the pandemic-imposed constraints on delivery of education is evidence of a collective national capability for improved responsiveness and adaptation to changing circumstances. Continuing to build on this momentum will enable the engineering education community to embrace future program developments.

> *'Most engineering schools have been investigating the potential of online learning and online teaching tools for many decades, however have not yet fully embraced this style of teaching and the advantages it brings. With the current situation, and the involuntary adoption of online teaching in most institutions, this has been forcibly changed, and many schools and academics are now seeing the benefits of this style of teaching and learning. There are opportunities to utilise these resources even when campuses reopen in order to leverage the benefits that they deliver, as well as opening up new possibilities for international education.'*

> *'The need for more flexibility and adaptiveness to changes (not just in learning and teaching area but also in preparation for different and new situations in workplaces i.e. working from home) is evident.'*

7.2 Review and revise programs, priorities and pedagogies

The exemplars presented in the previous sections are a snapshot of programs that members of the Australian and international engineering education community have identified as potentially future facing. Many of these programs embody a carefully designed set of authentic, experiential and hands on learning activities and carefully aligned assessments. Some are delivered to large cohorts.

Exemplar program characteristics can be categorised as follows.

i. A distinctive educational program level philosophy that frames engineering studies as:
    - i. socio-technical, human centred and a vehicle for positive world change,
    - ii. connected to professional practice and contemporary issues
    - iii. technical expertise deployed in multi-disciplinary contexts
    - iv. embracing contextual development of professional skills and attitudes
    - v. systematically building coordinated capabilities

ii. Strong program level frameworks for engagement with industry that includes the provision of work placements for work integrated learning and input to practice based courses.

iii. Collaborations with partner organisations from industry and the community including not for profit humanitarian organisations such as Engineers Without Borders (EWB).

iv. Curriculum contexts that are:
    - i. design and/or maker based
    - ii. project oriented
    - iii. multidisciplinary
    - iv. strongly connected with industry and community
    - v. globally oriented

v. Student centred active learning pedagogies such as:
    - i. work integrated learning
    - ii. PBL, and studios including collaborative team-based learning
    - iii. student led self-directed learning
    - iv. flexible delivery using on-line and blended learning, e.g. flipped classrooms
    - v. discovery led, just in time learning

These are systematically used throughout the exemplar programs beginning in the first year and incorporating industry-based and/or industry-sourced experiences, topics and projects including those that can be delivered to large (400 – 1,000+) cohorts. Ideally these learning experiences are:

i. realistic, multidisciplinary, and collaborative
ii. require innovation, creative input and decision-making
iii. focus on complexity including the United Nations Sustainable Development Goals
iv. may have an international dimension
v. make effective use of relevant educational technologies to deliver content just in time, and
vi. use assessment paradigms that consider reflective and project processes as well as end products: they do not use traditional end of semester written examinations.

vi. Assessments are

i. authentic
ii. cover coordination of multiple competencies
iii. include reflection

vii. Enabling people, processes, systems and resources are available including

i. teaching staff with expertise in relevant pedagogies
ii. external and industry practitioners
iii. organisational support for the:
1. coordination/leadership of multidisciplinary engagement,
2. development of internal expertise in teaching and learning and
3. external engagement in teaching programs

No single best practice model for future engineering education programs exists. There is no one size fits all model that can be prescribed. The opportunities and barriers will be defined by the identity and circumstance of each university. Further diversification of program models and approaches is to be encouraged.

Survey respondents appreciate that:

> *'there may be several "generic" ways of achieving the Engineering futures 2035 expectations, …..they will not be the same for all universities'.*

> *'Adaptiveness of program to circumstances and student and industry requirements is a relevant feature.'*

> *'one has to be careful not have the undergraduate engineering degree so focused on current industry practice (which is very helpful for immediate employment) that it becomes just an apprenticeship or we produce graduates who will have limited ability so(*sic*) adapt to expected future changes and disruption'.*

> *'For example, the German system has dual options for higher education qualification being through a "University" or "Fachschule or Technical School". The earlier being the classical broader university education which is highly regarded and graduates typically attract higher salaries and often work on more complex projects. The latter being practice focused with very close industry training and graduates who are also fully qualified engineers are typically more job ready. It is very difficult to try to do both in one degree and in a 4 year bachelor. As a profession and especially EA we need recognise and support that individuals and industry would need both types of graduates who are distinctly different.'*

7.3 Enable stronger engagement with professional practice

The strong response favouring practice focussed education in its various forms confirms a general view that greater future industry interaction and support is essential for embedding stronger exposure to professional practice and authentic learning experiences via: work placements, industry input into curriculum design, industry sponsored projects and industry practitioner involvement in teaching.

Although industry has a vital role to play it is also clear that at present *'industry can't or don't mentor student engineers in the same way the health sector supports developing professionals'.*

Is the size of the engineering student cohort an insurmountable issue? UTS, SUT and CQU run cooperative engineering education programs which involve extended periods of time in industry. The SUT Bachelor of Engineering (Honours)(Professional) program is relatively new having been fist implemented in 2017, whereas the UTS and CQU programs awards are long established and include a Diploma: the total graduate numbers from these two programs in 2019 being around 400 (ACED (December, 2020)).

The Medical Deans of Australia and New Zealand (2018) report that *'3,475 medical students graduated from Australian medical schools in 2017, of which 87% were domestic graduates'*. The number of graduate professional engineers in 2019 is significantly larger: based on figures in Table 2 of this report there were over 20,000 graduates from Bachelor (Honours) and coursework Master programs with 43% being domestic students. The majority (84%) of domestic graduates completed a Bachelor/Bachelor(Honours) degree. The scale involved in developing an engineering education apprenticeship model such as that used in medical education would be challenging. However, worthy of note are figures from the University of Waterloo that had over 7,000 engineering students enrolled in their co-operative education programs in 2019-2020. This is comparable with the total number of domestic Bachelor of Engineering graduates in 2019.

Given the large student cohorts in many of Australia's engineering universities survey participants advocated looking to successful providers of large-scale delivery co-op programs such as the University of Waterloo.

'This is already done at great scale, we need to learn from them how they have managed this'

Waterloo's cooperative education programs are run by a dedicated co-operative education department that is not tied to a single faculty, works with the faculties, employers and students, and is fully funded through co-op work term fees which are paid by students.

'Best Practice Guidelines for Effective Industry Engagement in Australian Engineering Degrees' by Male and King (2014) also explored ways in which *'Engineering curriculum design and delivery incorporate the spectrum of local and global engineering practice'.* The guidelines contain a range of exemplary models and supporting tools and resources. Recommendations for universities, industry, and professional bodies, industry organisations and government are provided. A summary listing of these recommendations is provided in Appendix 2 of this report.

The work undertaken in the Engineering Futures project confirms the need to enable stronger industry - university interactions and realise the full potential embodied in the recommendations made in this report and the Male and King Best Practice guidelines.

While cooperative education programs and programs incorporating extended industry placements and internships may set the gold standard for student engagement with professional practice, there are other useful forms of interaction that are also worthy of consideration.

Male and King (2019) updated their previous findings and looked at ways in which universities might address the decline in availability and issues with quality control of the traditional 12-week work experience that has been a graduation requirement for many Australian engineering programs. Complementing this paper is the Male and Valentine 2019 report on the study on Virtual Work Integrated Learning (VWIL) in engineering which investigated the potential of work that has been

'created for the purpose of learning rather than any true work for an employer or client….. In VWIL, students undertake learning activities that involve industry but are not true employment (paid or unpaid). Students complete authentic tasks, using authentic tools and/or processes, and engage face-to-face or electronically with real or simulated workplaces and/or practitioners. Compared with traditional WIL in engineering which had involved engineering-related work with an employer, virtual WIL would provide increased reliability and breadth, for larger numbers of students, throughout the program—from first to final year…..VWIL is a reliable, efficient, and scalable approach to support engineering students to learn about engineering practice and develop a wide range of employability skills.'

According to Male (2021, personal communication), *'The Virtual WIL project demonstrated that engagement with practice that is not real work for a company is feasible with hundreds of students. It is important to scale the commitment from industry partners with the year level of the students – from short time commitment reaching many students in first year, to long time commitment and deeper interaction with fewer students by final year. It is also essential to test plans and resources thoroughly, and to prepare all stakeholders before the learning activity, especially industry partners and sessional teaching staff. Tech support to reduce the concerns of teaching staff is also valuable.'*

PBL is also used to engage with industry and community. There are many examples of successful large-scale implementations in Australia and overseas.

*The (*UQ*) program has been developed addressing how to scale first year courses to large student cohorts… contains a set of innovative creative pedagogies… to bring a variety of competencies together.'…..*

Digital learning technologies have been instrumental in practice-based education programs and in successfully scaling up project-based learning to large cohorts such as those found in many first-year engineering courses in Australian and international universities that have flipped classrooms. Using on-line delivery of content has proved useful for codified learning and its assessment. The COVID-19 induced acceleration of universities moving to greater use on-line learning and assessment means engineering schools now have the opportunity to further refine their e-learning and e-assessments approaches. Just in time bite-sized delivery of on-line content and micro-credentialing can support more hands-on active learning whether this be in projects, laboratories and/or industry-based WIL.

Appropriate assessments and reflection especially those looking at multiple coordinated competencies are also integral to successful use of PBL. The processes by which outputs such as prototypes, models and reports are generated are significant learning outcomes in their own right and therefore need to be taught and assessed i.e. in a project-based courses, project management, team work and communication need to be assessed.

Strategic use of PBL needs to be integrated into a program level assessment plan.

'We need to rethink assessment in this process. Many of the technical skills can be easily tested by computer, thus reducing staff cost of marking exams. This enables staff to spend more time in one to one mentoring and coaching…. remove single/summative tasks such as end of semester exams; improve feedback; seek out more student led learning opportunities such as PBL/studio'

'Online invigilation systems come with their own range of issues if you want to stay in closed book assessments'

'The move to open book take home assessment has a number of challenges, including how to write these.'

'Learning contracts and portfolios are both means to get students focused on their personal learning journey. At the moment, our assessment processes do not really help students to see where they are in their own learning journey.'

'We are now in a good place to fundamentally change our approach to engineering education by using projects/studios + online learning. This is particularly true of the latter half of an engineering degree and is basically how capstone projects work.'

Recommendations 1 and 2 speak to the preceding discussion:

R1: Engineering education providers review and revise professional engineering education programs to embed a stronger focus on student engagement with contemporary engineering practice and its sociotechnical contexts.

R2: Engineering education providers review the exemplars profiled in this report and the Male and King 2014 report 'Best Practice Guidelines for Effective Industry Engagement in Australian Engineering Degrees' that identify the learning and assessment activities that engage students with professional practice and show this can be done in different ways and at scale.

7.4 Broaden the national range of programs and graduate outcomes

While a number of the international exemplars were recognised for the multidisciplinary approaches, especially in the context of design or through the inclusion of humanities and social science courses, little was heard about opportunities for engineering students to work with students from non-engineering disciplines that intersect with engineering practice as part of the formal curriculum. Given the significant numbers of domestic engineering students undertaking double degrees consideration should also be given to possible enhancements such as those outlined in section 5.2 that might be undertaken to the program architectures and/or contextualisation of double degrees to ensure and assure their contribution to the delivery of more diverse yet better articulated and synergistic graduate outcomes that will be expected from future professional engineers.

Is it also timely for engineering education leaders to consider the opportunity to introduce into Australia's suite of engineering programs new and different kinds of engineering degrees which focus more on multidisciplinary, entrepreneurial, innovative engineering applications and design, and/or more joint or double programs between engineering and design?

If an expanded range of Australia's engineering education programs is to attract greater numbers of students from more diverse backgrounds an appropriate communication and marketing strategy will be needed. This has been investigated and reported separately by Lawrence (2020).

Perceived accreditation risks associated with new and innovative programs, including double degree programs will need to be addressed in collaboration with Engineers Australia.

Recommendation 3 speaks to this issue:

R3: Engineering education providers act creatively to consolidate the professional and career benefits of existing double degree programs and proposed new engineering education programs that deliver significant broadening learning outcomes. Opportunities for broadening of program outcomes in existing programs should also be considered. This may involve structural changes to programs and assessments. Perceived accreditation risks be managed in cooperation with Engineers Australia.

7.5 Review approaches to staffing models and develop staff expertise in Teaching & Learning

Resources including the provision of adequate numbers of teaching staff with appropriate experience and expertise will need to be addressed especially if there is to be greater use made of practice-based pedagogies and project-based learning employing work integrated learning and multi-disciplinary projects.

> *'Lose the (all-rounder) 40:40:20 [workload allocation] model; favour a strengths-based approach – match academics preference/capability/aspiration to supporting student learning and assuring learning outcomes*
>
> *The champions/leaders in transitioning their T&L practice are already progressing rapidly. The gap/gulf between them and those who have not shifted is growing bigger.'*
>
> *'It is important for our academic facilitators to create the right environment for (studio/project) critique. Students should feel emotionally safe to share risky ideas without undue criticism. Similarly, academics need to have enough humility to realise that there are many possible solutions to a problem but also to have the confidence to nudge students and groups back on track when they have strayed too far from the brief.'*

When aligned with top-down program design the contribution to student learning could be significant.

> *'This includes mapping student journeys and improve service and customer experience strategies. With a clear handle on different types of students, who have different needs and abilities, teaching and academic support could be tailored specifically for their learning, rather than one size-fits all.'*

The following recommendations address system-level resource requirements to improve teaching and learning:

R4: Engineering education providers deploy adequate numbers of teaching staff with appropriate experience and expertise to enable R1 whether this be through greater use of practice-based pedagogies, or project-based learning, or work integrated learning or multi-disciplinary projects.

Augmentation of the academic workforce with the capability to deliver a stronger focus on practice and broadening outcomes has been consistent theme and is the subject of a separate tranche of work and report. See Reidsema et al. (2021).

R5: Funding from industry and government be sought to provide the resources to support the embedding in engineering education programs of a stronger focus on student engagements with professional engineering practice. An industry- university- government partnership model is envisaged.

7.6 Revise funding/budgeting models

A number of observations were also made in survey responses about University funding and budgets.

> *'the huge elephant in the room is the higher education funding issue.'*
>
> *'The Government's new funding model reduces income to universities for engineering programs which may also impact on what is possible'*
>
> *'Will students and the government continue to pay large amounts of money for a predominantly online experience?.'*
>
> *'Given the financial constraints we will be in for the foreseeable future, we have to address current (poor) practices in costing/budgeting academic activities including:*
>
> - *curriculum development – we typically make lengthy business cases for purchasing capital equipment, yet arguably the cost of program development and allocation of workload is poorly budgeted or allocated – similarly for ongoing program O&M;*
> - *various forms/type of delivery (e.g. weekly modes including 'lecture/tutorial/lab), micro-credential; studio; WiL support/engagement; project supervision; short-course/enterprise learning; offshore program delivery; subject coordination; student consultation… That is, all these rely on (say) discipline expertise of the academic, but their practice in each needs to be different in each. It could help transition academic practice by having expectations of their work clearly articulated.'*
>
> *'Education in Australia has become too expensive. Education needs to transform their operations, moved to new work practices, stop building iconic structures and incorporate real change (not cosmetics) in universities. Non-academic cost could be brought down significantly with decisive leadership and experience from other parts of the economy. Transform the way universities operate and stop tiptoeing around obsolete ways of doing things'*
>
> *'Diversify international student markets. Reliance on a small number of countries and high fees should be discontinued.'*

7.7 Share good practice and build alliances

Sharing good practice and alliances with other organisations and universities is a feature of iconic education experiences in a number of the cited exemplars. This was also a strong theme emerging from the survey responses ranging in scope from interest in interdepartmental to national cooperation on development of course teaching and assessment materials to national sharing of programs to joint international education activities.

Australia's best known example of joint curriculum development and delivery is probably the Mining Education Australia (MEA) initiative involving the Minerals Tertiary Education Council (MTEC) and several Australian universities providing a mining engineering program. Another alliance is the Australian Power Institute (API) sponsored by companies in the electric power industry to support power engineering education and '*coordinate industry and university innovation initiatives*'. https://api.edu.au/

MOOC's, SPOC's and micro credentials are increasingly being recognised as valid forms for earning academic credit in higher education. Given the COVID-19 induced transition to greater use of on-line learning

> *'There may be opportunities to more openly share emerging educational approaches which better address the needs of the Australian economy and workforce'*
>
> *'Could we develop together, a suite of great new online subjects that could be offered across multiple institutions? Maybe this has been tried before – but I think everyone would be more open to this now.*
>
> *We could then get a critical mass of champions and innovators and leaders working together on subjects that are hard to run within one institution because of a lack of expertise or other things. It could be done with an "exchange" model so it does not involve finances.*
>
> *Perhaps the online could be complemented by an in-person summer school where students can take 1-2 subjects from a selection. Emphasis on innovative subjects delivered by our best engineering educators. This also serves to acknowledge those doing great things.'*
>
> Is it also timely *'to consolidate the variety of programs that we offer across the country. What if we had 5 or 6 civil engineering programs and not 30+? Deans could collaborate in consortia – find kindred faculties to co-develop the basic modules as well as inspirational projects that would develop the full range of graduate capabilities.'*
>
> *'It's quite possible that we could return to a pre-1975 model of learning engineering, rather similar to the CSU model. Students would spend 2-3 semesters at university getting some basics and then join organisations as cadet engineers, learning on the job via projects supported by online modules of content. It is quite possible this would radically change the business model of engineering faculties.'*
>
> *'Initiatives that link student groups from different countries/regions in joint learning activities will grow.*
>
> *This approach may come with a downside in that it will become more challenging to provide authentic hands-on project work with a distributed cohort. Engineering companies are having to work this way and it is an area that higher education will need to explore.'*
>
> *''International and national cooperation/building synthesis programs as others become more targeted and leaner based on major market strengths (rather than generalist degrees). There are developments of new universities on the edges of innovation where partnerships could be formed too (e.g. Plaksha.org) where reimagining is taking place'*

Developing a nationally coordinated initiative in conjunction with industry and government that enables greater engagement of engineering students in professional practice via cooperative education programs, work integrated learning programs and industry placements could only be considered if there was substantial collaboration and cooperation from engineering education providers.

The experiences of those involved in managing disruptive change suggest that this will succeed only with substantial levels of ownership and cooperation between all stakeholders. Such cooperation has traditionally been challenging for universities who compete with one another for students and funding.

Recommendation 6 speaks to this issue:

R6: Engineering education providers cooperate to build the network and alliances needed to effect the changes required to deliver on the preceding recommendations.

National leadership of a deliberative process, collective ownership, and oversight of change management is needed.

As reported in the scoping study (Crosthwaite, 2019) urgent action is needed if engineering education is to make the changes needed to deliver on the Engineering Futures 2035 needs.

> *'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'.*

Recommendation 7 speaks to this issue.

R7: Work on the preceding recommendations begins now. Major cultural shifts are involved in making the recommended changes. Even with coordinated and determined effort the transition from the present to the Engineering Futures of 2035 will take many years.

While the preceding recommendations speak directly to education providers their realisation must engage a broader range of stakeholders and associated issues. This is addressed in the combined Engineering Futures 2035 Final Report. The final report brings together the three tranches of work on; perceptions and promotion of engineering (Lawrence (2020)), engineering education programs and pedagogies (this report), and the engineering educator workforce (Reidsema et al. (2021) and ensuing calls for action.

8. Recommendations

R1: Engineering education providers review and revise professional engineering education programs to embed a stronger focus on student engagement with contemporary engineering practice and its sociotechnical contexts.

R2: Engineering education providers review the exemplars profiled in this report and the Male and King 2014 report 'Best Practice Guidelines for Effective Industry Engagement in Australian Engineering Degrees' that identify the learning and assessment activities that engage students with professional practice and show this can be done in different ways and at scale.

No single, unique model will suit all providers, and a blending of models to suit individual provider circumstances that leads to national diversity in delivering on R1 is encouraged.

R3: Engineering education providers act creatively to consolidate the professional and career benefits of existing double degree programs and proposed new engineering education programs that deliver significant broadening learning outcomes. Opportunities for broadening of program outcomes in existing programs should also be considered. This may involve structural changes to programs. Perceived accreditation risks be managed in cooperation with Engineers Australia.

R4: Engineering education providers deploy adequate numbers of teaching staff with appropriate experience and expertise to enable R1 whether this be through greater use of practice-based pedagogies, or project-based learning, or work integrated learning or multi-disciplinary projects.

Augmentation of the academic workforce with the capability to deliver a stronger focus on practice and broadening outcomes has been consistent theme and is the subject of a separate tranche of work and report. See Reidsema et al. (2021).

R5: Funding from industry and government be sought to provide the resources to support the embedding in engineering education programs of a stronger focus on student engagements with professional engineering practice. An industry- university- government partnership model is envisaged.

R6: Engineering education providers cooperate to build the network and alliances needed to effect the changes required to deliver on the preceding recommendations.

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- Dr Mark Symes
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Appendix 1: List of Survey Participants and Contributors

Australian University survey participants

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Appendix 2: Recommendations from: Best Practice Guidelines for Effective Industry Engagement in Australian Engineering Degrees

(adapted from Male and King (2014))

Recommendations for Engineering Faculties

F1. All engineering faculties will establish and maintain effective industry engagement as part of faculty culture.

F1a. All engineering faculties will establish people, processes, and resources to ensure strong relationships with industry

F1b. All engineering faculties will provide structural and developmental support for academics to engage with industry

F1c. All engineering faculties will engage engineers with industry experience in facilitating learning

F1d. Industry consultation will be structured and transparent

F2. All engineering programs will use industry-based assignments

F3. All student engineers will have substantial opportunities to work and learn in industry

F4. High percentages of students will have opportunities to undertake industry-based final year (capstone) projects

F5. Emulated work-integrated learning will be developed as an example of effective industry engagement

F6. Students will be encouraged to take responsibility for seeking opportunities to learn about engineering practice

F7. Engineering faculties will support and recognise industry engagement undertaken by student groups

Recommendations for Industry

I1. Organisations should provide regular and structured student engineer employment

I2. Engineering employers should provide support for their engineers to engage with engineering education

I3. Engineering employers should provide support for academics to experience industry

Recommendations for Professional and Industry Bodies, and Governments

B1. Industry bodies, universities, student societies, and the Australasian Association for Engineering Education, should consider establishing a resource centre to support industry engagement with universities

B2. Government, professional bodies, and engineering faculties should consider establishing a joint internship scheme

B3. Engineers Australia should consider developing an e-portfolio resource for student engineers

B4. Industry bodies should foster a culture of industry engagement with education

B5. Government should consider incentives for employers to support engineering education

B6. The engineering program accreditation board should review the accreditation guidelines with respect to exposure to engineering practice

Definitions and Acronyms

ABET: Accreditation Board for Engineering and Technology, USA

ACED: Australian Council of Engineering Deans

ANU: Australian National University

API: The Australian Power Institute

BEPH: Bachelor of Engineering Practice (honours) at SUT

CSU: Charles Sturt University

EA: Engineers Australia

EPA: Engineering Practice Academy, Swinburne University of Technology

EWB: Engineers without Borders

GEP: Global Engineering Program, Stanford University

IEA: International Engineering Alliance

IEP: Integrated Engineering Program, University College London

MIT: Massachusetts Institute of Technology

MOOC: massive open on-line course

NEET: New Engineering Education Transformation, MIT

NMITE: New Model Institute for Technology and Engineering

NUS: National University of Singapore

MEA: Mining Education Australia

MTES: Mineral Tertiary Education Council

PBL: Problem based learning organised through project-based learning

QILT: Quality Indicators of Teaching and Learning

SPOC: small private on-line course

STEM: Science, technology, engineering and mathematics

SUT: Swinburne University of Technology

SUTD: Singapore University of Technology and Design

UCL: University College London

VIP: Vertically Integrated Projects/Program

WIL: work integrated learning