The global state-of-the-art in engineering education

Outcomes of Phase 1 benchmarking study

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Executive Summary

In June 2016, MIT launched the New Engineering Education Transformation (NEET), an initiative charged with developing and delivering a world-leading programme of undergraduate engineering education at the university. To inform this programme of reform, MIT commissioned a benchmarking study to provide a rapid overview of the cutting edge of engineering education globally and a horizon scan of how the state-of-the-art is likely to develop in the future. The study focuses on engineering education at the undergraduate level.

This report presents key findings of the benchmarking study. It draws on interviews with 50 global opinion leaders in engineering education located in 18 countries. The report addresses four key questions:

1. **Which institutions worldwide are considered to be the current leaders in engineering education?** Olin College of Engineering and MIT were both cited by the majority of thought-leaders to be the 'current leaders' in engineering education, with other highly-regarded universities including Stanford University, Aalborg University and TU Delft. Many interviewees noted that the engineering education sector was entering a rapid period of change and they therefore anticipated considerable movement in global leadership in the coming years.

2. **Which institutions worldwide are considered to be emerging leaders in engineering education?** A number of institutions – including Singapore University of Technology and Design, Olin College of Engineering, University College London, the Pontifical Catholic University of Chile and Iron Range Engineering – were consistently cited by interviewees as global 'emerging leaders' in engineering education. Recommendations overall focused on a new generation of engineering programmes, many of which were developed from a blank slate or the product of systemic educational reform, that were often shaped by specific regional needs and constraints. The institutions selected as 'emerging leaders' by thought-leaders point to a shift in the centre of gravity of the world's leading engineering programmes from north to south and from high-income countries to the emerging economic 'powerhouses' in Asia and South America.

3. **What key challenges are likely to constrain the global progress of engineering education?** Despite the geographic spread of the thought-leaders consulted, a common set of barriers to progress was identified. Barriers included the siloed mono-disciplinary structure of many engineering schools and universities, faculty appointment and promotion systems that were not perceived to reward teaching

achievement, the challenge of delivering active learning to large student cohort sizes and aligning government and higher education goals

4. **How is engineering education worldwide likely to develop in the future?** Many of the features anticipated to characterise the leading engineering programmes of the future were evident amongst universities identified as 'emerging leaders' in the field. These included (i) the blending of resource-intensive on-campus active learning experiences with tailored off-campus online learning, (ii) an increase in choice, flexibility and diversification offered to students in their engineering studies, and (iii) curricula that bring together the themes of cross-disciplinary learning, human-centred engineering and global experiences.

The report also discusses the **measurement of quality in engineering education**. The thought-leaders pointed to the weaknesses of available metrics and noted the informal indicators on which they relied. The most important of those was the institution's capacity to deliver world-class education, as reflected in its institutional commitment to education, its educational culture and its influence on educational practice worldwide.

The second phase of the study, to be conducted in 2017, will provide case study evaluations of 'current leaders' and 'emerging leaders', selected to offer particular insights to both MIT and the wider engineering education community.

Acknowledgements

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1. Introduction

1.1. Aims of the study

In June 2016, MIT launched the New Engineering Education Transformation (NEET), an initiative charged with developing and delivering a world-leading programme of undergraduate engineering education at the university. Building on MIT's established educational strengths, NEET responds to the challenges and opportunities facing the next generation of MIT graduates.

To inform this programme of reform, MIT commissioned a benchmarking study to provide a rapid overview of the world's leading engineering education programmes. The study has been designed in two phases. The first phase was conducted between September and November 2016 and offers a snapshot of the cutting edge of global engineering education and a horizon scan of how the state-of-the-art is likely to develop in the future. The second phase of the study, to be conducted in 2017, will involve an evaluation of selected institutions identified during Phase 1 that may provide particular insights to both MIT and the wider engineering education community.

This report provides a summary of the first phase of the study. Drawing on feedback from 50 global opinion leaders in engineering education, it addresses four questions:

1. Which institutions worldwide are considered the current leaders in engineering education?
2. Which institutions worldwide are considered the emerging leaders in engineering education?
3. What key challenges are likely to constrain the global progress of engineering education?
4. How is engineering education worldwide likely to develop in the future?

The study focused on the quality/performance of engineering education at the undergraduate level. Its scope therefore did not include educational research/scholarship, postgraduate study or other factors not directly related to the quality of undergraduate education as experienced by the students enrolled.

1.2. Study approach

The Phase 1 study drew on one-to-one interviews with individuals recognised to be thought-leaders in the field of engineering education as its primary data-gathering tool. This set of opinion-leaders included pioneers in engineering education research, policymakers in the field and university leaders with direct experience of delivering the world's most highly-regarded engineering education programmes. By bringing together the perspectives and insights of this respected group of global experts, the study provides a map of global best practice in engineering education and the future direction of the field.

Initial targets for interview were identified through a review of the literature and the author's existing connections with the international engineering education network. A snowballing method was used to identify further individuals for consultation, with the initial group asked to identify other international thought-leaders who should be consulted in the study. Priority was given to thought-leaders recommended by three or more interviewees.

A total of 50 thought-leaders from 18 countries were successfully interviewed. Their geographical location is indicated in Figure 1. US-based interviewees represented the single largest group of experts, a weighting that reflects the frequency with which US-based individuals were recommended as global thought-leaders. A full list of the 50 individuals consulted in the study is provided in Appendix A.

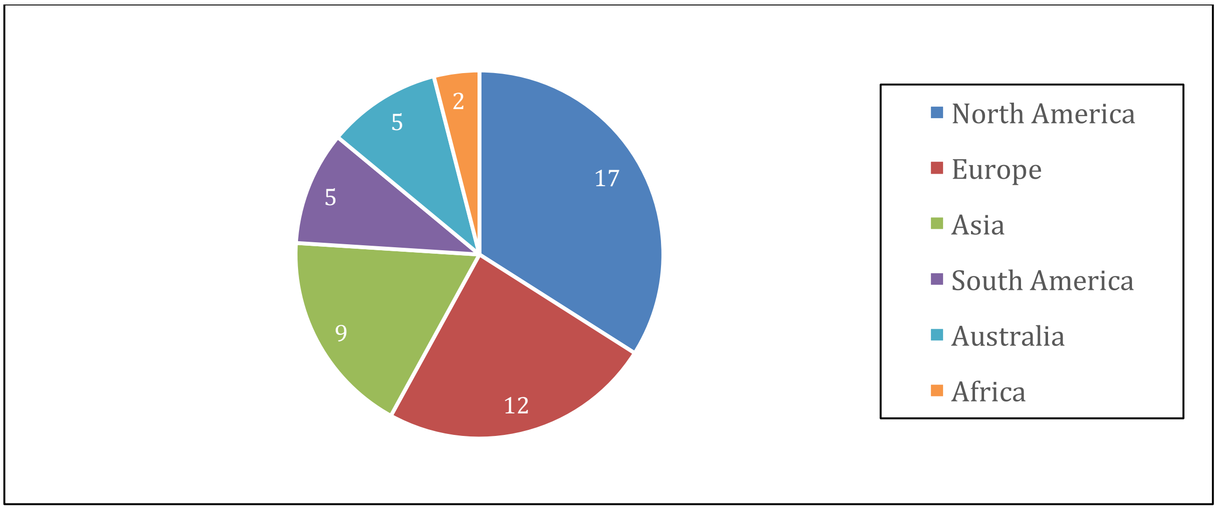

Figure 1. Breakdown of interviewees by geographical location

Interviews were one-to-one and conducted in English. The questions used to frame the semi-structured interviews were sent to all individuals in advance. A common set of questions was asked of all interviewees (Appendix B) with additional questions included for individuals with relevant specialist knowledge (in areas such as engineering design or the measurement of educational impact). Most interviews lasted between one and two hours, although two were 30–40 minutes in duration. Three individuals chose to respond to the questions in writing.

Quotes from the 50 interviews are used throughout the report to illustrate the common views and themes that emerged. Anonymity was protected: interviews took place on the understanding that information or opinions would not be attributed to named individuals in the report unless permission was given by those consulted.

The interview data captured from the thought-leaders were complemented by a snapshot literature search and review on the state-of-the-art in engineering education. This synthesis of current knowledge was used to provide contextual information about the best practice programmes highlighted during the consultations. Additional consultations were also undertaken with nine individuals to capture information about specific pedagogical approaches or programmatic details that had been highlighted as particular areas of interest during the interviews with thought-leaders.

1.3. Focus of the report

The 50 thought-leaders were asked to identify the universities that they considered to be (i) current world-leaders in engineering education, and (ii) emerging world-leaders in engineering education. In both cases, interviewees were asked to identify institutions rather than programmes or courses, enabling their recommendations to be combined into institutional 'rankings' for both the *current leaders* and *emerging leaders*, as presented in **Section 2** and **Section 3** respectively. These sections also draw out some of the common features evident across these two groups of highly-cited institutions, with Appendices C and D highlighting selected interviewee feedback relating to each.

Section 4 describes the selection criteria used by interviewees to distinguish the 'current leaders' and 'emerging leaders' and outlines current practices in the measurement of quality and impact in the field.

Section 5 summarises the key barriers identified as constraining the ability of engineering schools and universities to improve their undergraduate programmes.

Section 6 outlines the features that were anticipated to characterise the world's leading engineering programmes of the future.

Section 7 provides concluding comments.

2. Who are the current leaders in engineering education?

2.1. The ‘top 10’ institutions

The 50 thought-leaders were asked to identify and describe the five or six universities that they considered to be the current global leaders in engineering education.

In all, 81 universities from 22 countries were identified by the 50 thought-leaders. The 10 institutions most consistently cited as ‘current leaders’ are presented in Figure 2. It highlights two US-based institutions that were each identified by over half of those consulted – Olin College of Engineering and MIT. The group of universities that just fell short of this ‘top 10’ list included Harvey Mudd College, Singapore Polytechnic, Nanyang Technological University and Imperial College London.

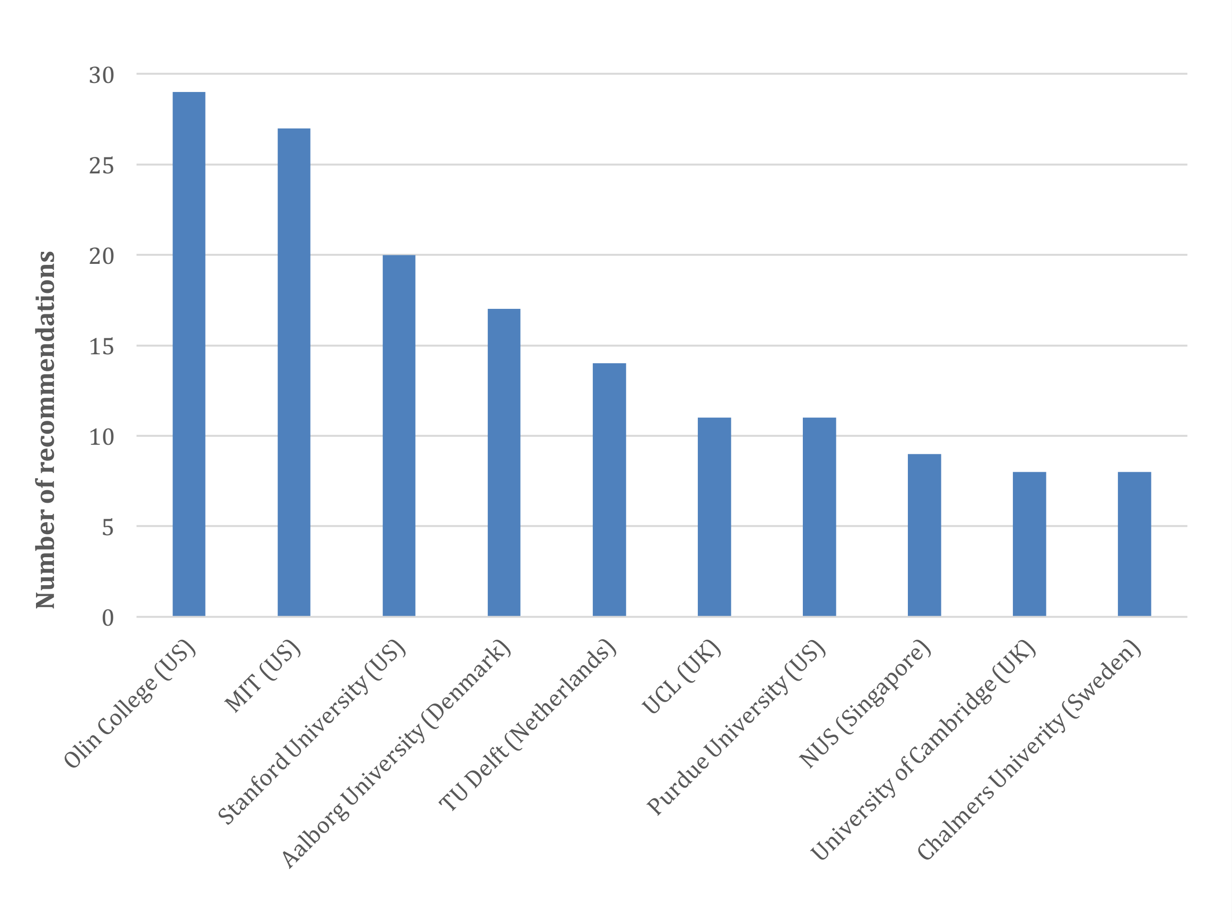

Figure 2. The 10 institutions most frequently identified as current leaders in engineering education

An analysis of the selections revealed that US-based individuals were disproportionately likely to identify US-based universities as ‘current leaders’: 66% of the ‘current leaders’ selected by US-based interviewees were from the US. This pattern was not evident amongst interviewees from countries outside the US: only 18% of their selections were for institutions in the continent in which they were based.

To ensure that the top 10 list of 'current leaders' was not unduly influenced by this potential bias, the data were reanalysed to take account of the individuals' country of residence. This second analysis excluded recommendations made by interviewees within their own country of residence. To protect anonymity, the analysis is presented in summary form only in Figure 3. The top 10 institutions identified as 'current leaders' remained unchanged following the re-evaluation. However, the positions held by both Purdue University and Stanford University were lower in the revised ranking. The premier positions held by both Olin College of Engineering and MIT remained unchanged, although their ranked order was reversed, perhaps reflecting the fact that non-US interviewees were more likely to identify Olin College as an 'emerging leader' rather than a 'current leader'.

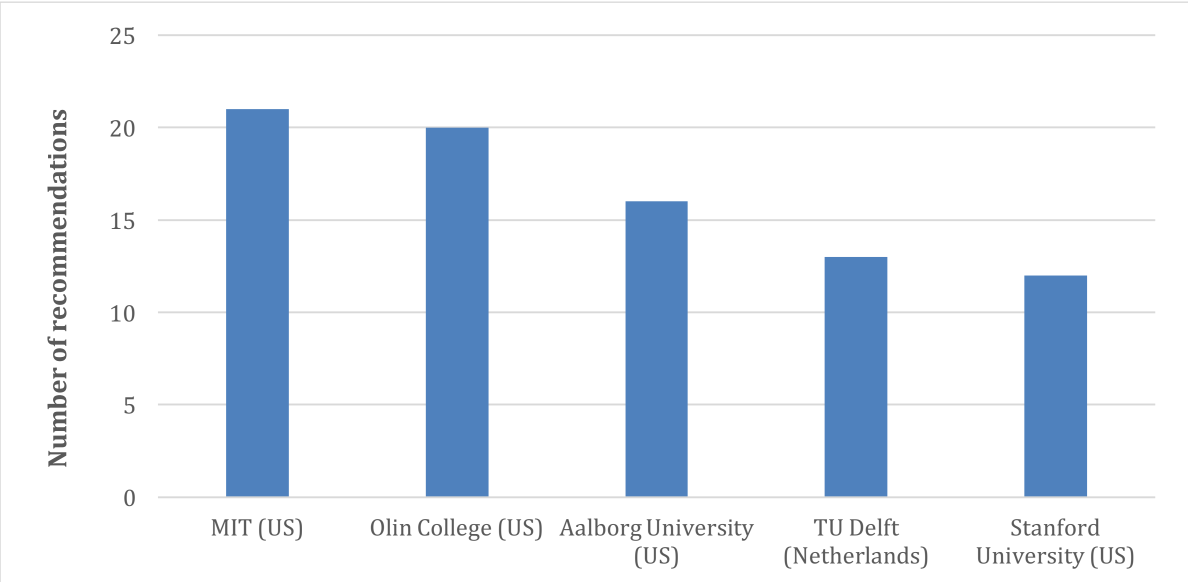

Figure 3. The 5 institutions most frequently identified as current leaders in engineering education, with the results adjusted for the country of residence of the interviewee

In describing their institutional selections, around half of the interviewees went on to suggest that the engineering education sector was entering a period of rapid and fundamental change. As a result, many suggested that the universities they identified as world leaders were likely "*to be quite different in five years' time to what they are now, because the benchmark of what constitutes good practice is changing*". As one interviewee commented:

> "*For years and years, there was endless talk about why engineering education needed to change, lots of statements and reports about what needed to be done. And nothing changed, give or take a few electives and new mission statements... [but in recent years] something has happened, things are happening in places you have never even heard of, all over the world. Doing the same old thing is suddenly not going to be good enough*".

Interviewees also suggested that these transitions were not confined to engineering: quality and impact in undergraduate education were becoming increasing priorities across the sector. Some interviewees noted the increased emphasis given by university leaders, including presidents, vice chancellors and senior managers, to their institution's educational vision and strategy. For example, one interviewee reported that, in the past, "*the conversations I had with deans, with university presidents, started and ended with research…[but now] they are talking about their teaching: what they are doing, what they are changing*". Others, however, also noted the difficulty in "*knowing what really goes on in the classroom*" at other institutions and being able to "*distinguish the rhetoric from the reality*".

As a result, it was suggested that most attention will continue to be paid to "*universities at the top of the [international] rankings and the universities on the conference circuit*" with good practice elsewhere often overlooked. For example, a number of interviewees noted that "*there is a lot of fantastic stuff going on in Germany – some great work collaborating with industry and a lot of investment [in higher education] from the German Government – but very rarely do they come out and talk about what they do, so I would not know which places to recommend*".

2.2. Common features of the 'current leaders'

The institutions consistently identified by interviewees as current 'world leaders' share a number of common features:

- ***established international profile***: the majority are well-established public universities catering for relatively large cohorts of undergraduate engineering students. A significant overlap is apparent between the institutions most frequently cited by interviewees to be 'current leaders' in engineering education (see Figure 2) and the international university rankings – indeed four of the universities listed in Figure 2 (MIT, Stanford University, UCL and the University of Cambridge) are also in the top 10 of the 2016 QS World University Rankings.[1]
- ***external engagement and educational collaborations***: the majority of the 'current leaders'– particularly the five most frequently cited universities – have been actively engaged in disseminating their ideas and practices across the international higher education community. In addition, most have strategic global partnerships to support the development of undergraduate engineering programmes elsewhere. Examples include the *Collaboratory*[2] at Olin College of Engineering, the *Conceive, Design,*

[1] QS World University Rankings 2016 (http://www.topuniversities.com/university-rankings/world-university-rankings/2016)

[2] Collaboratory, Olin College of Engineering (http://www.olin.edu/collaborate/collaboratory/)

Implement and Operate (*CDIO*)[3] initiative established and co-led by MIT, *Epicenter,*[4] operating until recently at Stanford University and the *UNESCO Centre for Problem-Based Learning*[5] at Aalborg University.

- ***educational excellence often confined to 'pockets'***: many interviewees noted that the good practice that helped to make a university world-leading in engineering education was rarely institution-wide: "*so much of these things are pockets, it is one programme or one department. Unless it is a new university, like Olin, there are not many places where the whole university is a leader*". Another described the educational practices at the 'current leader' institutions as "*a lot of bright spots of activity, but nothing coherent*". Educational cohesion was seen as a particular challenge in countries such as the US where individual faculty autonomy plays a significant role. Indeed, a number of interviewees noted that "*European universities, like Aalborg, Delft, Chalmers and KTH seem to have been able to take a more coordinated approach, a more consistent approach*". However, feedback – both from interviewees based at the top-cited 'current leader' institutions and external observers – suggested that, regardless of location, most are "*finding it difficult to propagate the ideas, the culture, the good practice out from the pockets of excellence. This is going to take some time and a lot of effort*".

In addition to these commonalities in profile and structure, similarities in educational approach were also apparent amongst the 'current leaders', as outlined in the box below.

Pedagogical features of the 'current leaders' in engineering education:

- pathways and linkages for students to engage with the university's research activities, often building upon rigorous, applied teaching in the engineering fundamentals;
- a wide range of technology-based extra-curricular activities and experiences available to students, many of which are student-led;
- multiple opportunities for hands-on, experiential learning throughout the curriculum, often focusing on "*problem identification as well as problem solution*", and typically supported by state-of-the-art maker spaces and team working areas;
- the application of user-centred design throughout the curriculum, often linked to the development of students' entrepreneurial capabilities and/or engaged with the social responsibility agenda;
- emerging capabilities in online learning and blended learning;
- long-standing partnerships with industry that inform the engineering curriculum as well as the engineering research agenda.

[3] CDIO (Conceive, Design, Implement and Operate) (http://www.cdio.org)

[4] Epicenter, Stanford University (http://epicenter.stanford.edu)

[5] Aalborg Centre for Problem Based Learning in Engineering Science and Sustainability under the Auspices of UNESCO (http://www.ucpbl.net)

2.3. Feedback on the top-rated institutions

Appendix C highlights selected interviewee feedback on the top eight universities most frequently cited as 'current leaders' in engineering education (see Figure 2):

- Olin College of Engineering
- MIT
- Stanford University
- Aalborg University
- Delft University of Technology (TU Delft)
- University College London (UCL)
- Purdue University
- National University of Singapore (NUS)

While the summaries generally reflect the balance of views expressed by interviewees and focus on the feedback most commonly given, critical feedback has not been included in this version of the report. For newer institutions, or those that have recently implemented a programme of educational reform, some contextual information is also included in the descriptions.

3. Who are the emerging leaders in engineering education?

3.1. The 'top 10' institutions

Thought-leaders were asked to identify and describe the five or six universities that they consider to be the 'emerging leaders' in engineering education: the institutions that look set to rise to the cutting-edge of engineering education worldwide in the decades to come.

In all, 89 universities from across 27 countries were identified. The 10 universities most frequently cited are presented in Figure 4. The group of universities that just fell short of this 'top 10' list included Monterrey Tech, Hong Kong University of Science and Technology, RWTH Aachen University and Nanyang Technological University.

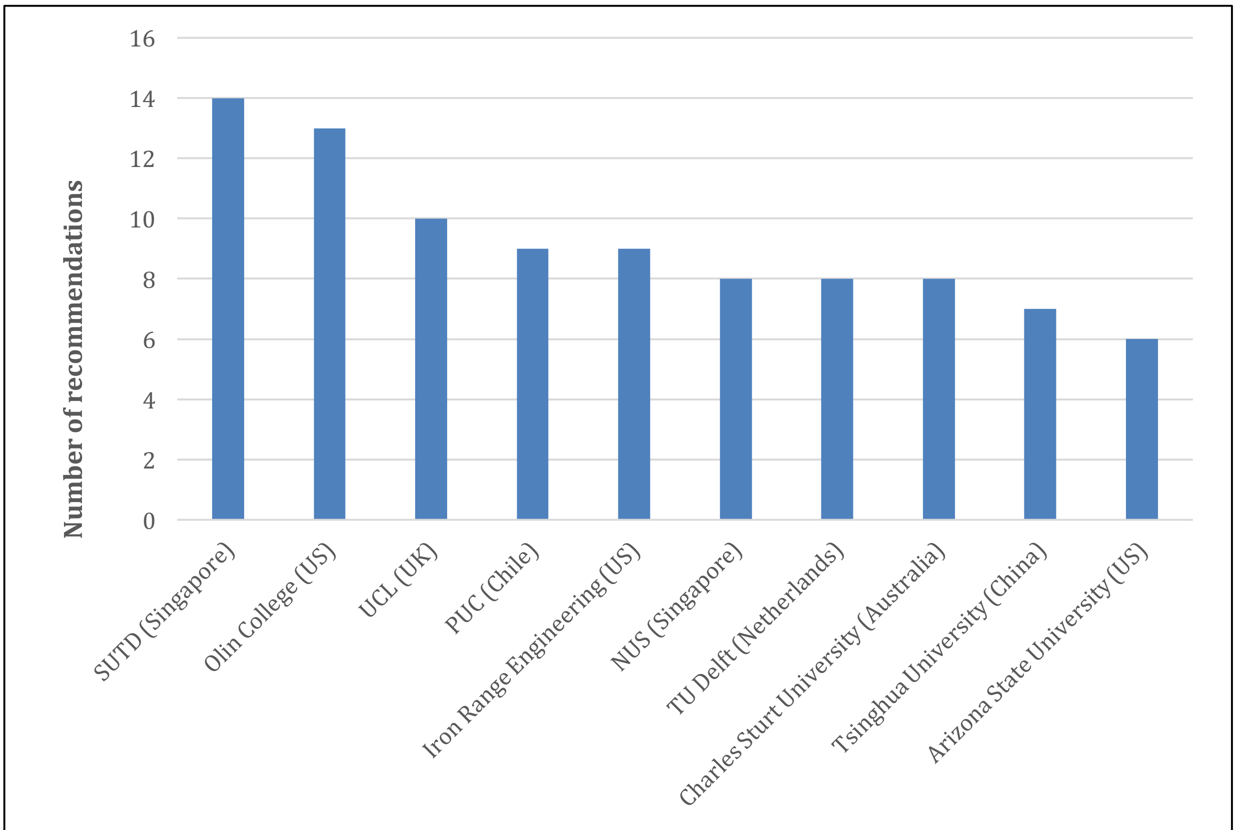

Figure 4. The 10 most frequently-identified emerging global leaders in engineering education

Four institutions feature prominently amongst both the current and emerging global leaders. While some interviewees identified Olin College of Engineering, NUS, UCL and TU Delft as 'current leaders', others (particularly those that were not national or regional peers to these universities) viewed them as 'emerging leaders'. This suggests that the ranked position of these four institutions could have been even higher if their status as either a 'current leader' or 'emerging leader' could have been allocated more consistently. Overall however, the Singapore University of Technology and Design (SUTD) and Olin College of Engineering were the institutions most frequently cited as 'emerging leaders' in engineering education.

A number of institutions were also repeatedly discussed by interviewees as ‘places to watch for the future’, but were seen to be at too early a stage of development to yet identify as ‘emerging leaders’. Examples are given in the box below.

‘Places to watch’

- NMiTE,[6] UK, a teaching-only engineering and technology institution currently under development, with a focus on creativity, innovation and experiential learning and aiming to admit its first cohort of students in 2019;
- the Lassonde School of Engineering[7] at York University (Canada), a new engineering school that aims to educate ‘renaissance engineers’[8] and admitted its first undergraduates to its programmes in 2013;
- BVB College[9] (India) which transformed its undergraduate curriculum to focus on social and technological innovation in a multi-disciplinary learning environment;
- the new engineering school at Insper[10] in Brazil which has developed a new hands-on, student centred curriculum.

3.2. Common features of the ‘emerging leaders’

The world’s ‘emerging leaders’ share a number of common features that may indicate the direction of travel for engineering education worldwide.

The **first feature** that connects most of the institutions in Figure 4 is their systemic and unified approach to engineering education. The majority of ‘emerging leaders’ fall into one of two categories:

- *New start*: a university or engineering school established from a blank slate with a distinctive and integrated educational approach, such as SUTD, Olin College of Engineering, Iron Range Engineering and Charles Sturt University;
- *Systemic reform*: a university or engineering school with an established global reputation engaging in a systemic programme of educational reform, such as UCL, PUC and Arizona State University.

Interviewee feedback suggests that such a unified and consistent educational approach – one reaching across all engineering undergraduate programmes – is not a feature of the majority of the ‘current leaders’.

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[6] New Model in Technology & Engineering (NMiTE), UK (http://nmite.org.uk)

[7] Lassonde School of Engineering, York University (http://lassonde.yorku.ca)

[8] Club Lassonde, Lassonde School of Engineering (http://clublassonde.com)

[9] B. V. Bhoomaraddi College of Engineering and Technology, India (http://www.bvb.edu)

[10] The new way to teach engineering, Insper, Brazil (http://www.insper.edu.br/en/newsroom/insper-in-the-media/the-new-way-to-teach-engineering/)

The **second feature** common to the ‘emerging leaders’ is an educational approach that distinguishes them from the ‘current leader’ institutions. While the elements of this approach varied across the ‘emerging leaders’, they included at least three of the following:

- non-conventional student entry requirements or selection processes;
- the increasing integration of work-based learning;
- the blending of off-campus online learning with on-campus intensive experiential learning;
- the establishment of student-led, extra-curricular activities in contexts and cultures that are not typically associated with non-curricular experiences;
- a dual emphasis on engineering design and student self-reflection that are integrated across the curriculum.

These elements combined in ways that marked a distinctive break with the educational approaches of the ‘current leaders’.

The **third feature** connecting many of the ‘emerging leaders’ is the extent to which their development has been shaped by regional needs and constraints. For example:

- the root-and-branch educational reform in the School of Engineering at the Pontifical Catholic University of Chile (PUC)[11] has been accelerated by significant government investment aimed at catalysing a new generation of technology innovators to drive the national economy and improve social mobility;
- the new engineering school at Charles Sturt University[12] (Australia) was established in direct response to the regional shortage of engineers with transferable and entrepreneurial skills;
- the educational transformation in the engineering school at Arizona State University[13] (US) has been focused specifically on supporting the health, opportunity and economic development of the state of Arizona.

Interview feedback suggests that the clarity of educational goals amongst these institutions – be that of national economic development, tackling societal inequalities of opportunity or improving the regional engineering skills base – has enabled them to take a more visionary and innovative approach, one that would not have been possible if the focus of reform had simply been on “*updating the catalogue*”.

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[11] Clover 2030, Pontifical Catholic University of Chile (http://www.ingenieria2030.org)

[12] CSU Engineering, Charles Sturt University (http://www.csu.edu.au/go/engineering)

[13] Ira A. Fulton Schools of Engineering, Arizona State University (https://engineering.asu.edu/#)

The **fourth feature** of the 'emerging leaders' is their geographical location and how that contrasts with 'current leaders' in engineering education. Figure 5 presents data for all of the recommendations made by interviewees, in both the categories of 'current leaders' and 'emerging leaders', by global region. As this illustrates, institutions identified as the world's 'current leaders' in engineering education are predominantly based in the US or Europe (representing 54% and 29% of the total recommendations made, respectively, and totalling 83% in all). In contrast, the 'emerging leaders' are much more likely to include Asian-based universities (increasing from 13% to 32% of the total selections made) and South American-based institutions (increasing from 3% to 11% of the total selections made). The geographical centre of gravity of the world's leading engineering programmes may therefore be undergoing a fundamental shift, from north to south and from established high-income countries to the emerging economic 'powerhouses' in Asia and South America.

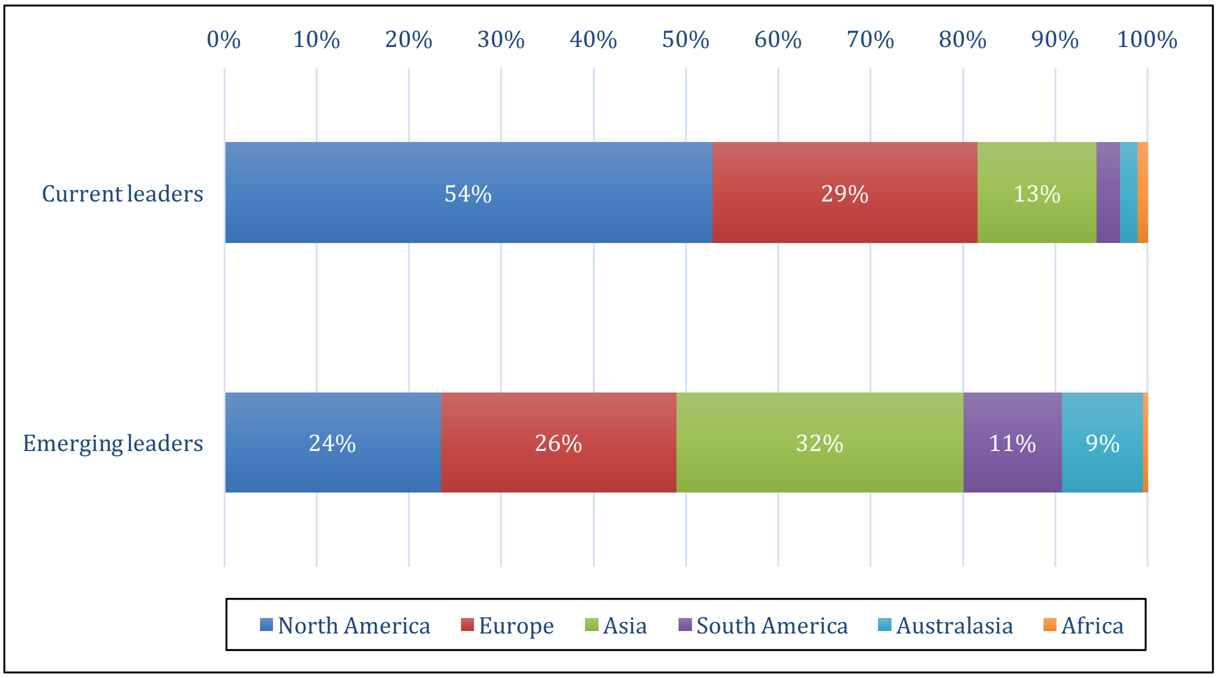

Figure 5. The locations of all recommendations made for current and emerging leaders

Although only one Latin American University features amongst the top 10 of 'emerging leaders', a range of other institutions in Brazil, Colombia, Mexico and Chile were consistently identified by interviewees. The transformations underway in Chile were particularly noted. As one interviewee commented, "*what I see universities doing across Chile – from the most elite research universities through to mid-range regional universities – is just phenomenal… It is an all-out effort, implemented with not only a vision, but with what people are doing on the ground*".

Almost a third of universities identified as 'emerging leaders' were based in Asia. As one interviewee noted; "*there has been an unprecedented expansion of higher education in South East Asia, and engineering education is at the core of that. There is going to be* *interesting things coming out of those parts of the world*". Indeed, many interviewees at a dean or university senior management level spoke about "*spending quite a lot of time in the Asian part of the world recently… Other countries are not losing momentum, but there is a strong realisation in many Asian universities that strength in research needs to be balanced by strength in education and there are real opportunities there*". A theme repeated by many interviewees was that while "*the teaching and the curriculum is not yet what I would call cutting edge*", it was the speed and direction of travel in many key Asian universities that was the source of particular interest. Many noted the significant investment in engineering education in both China and Korea and the potentially disruptive influence of new private universities in India. However, it was Singapore that was discussed most frequently. Indeed, over 60% of interviewees identified at least one of four Singaporean institutions – SUTD, NUS, Nanyang Technical University (NTU) and Singapore Polytechnic – either as a 'current leader' or an 'emerging leader' in engineering education. Benefitting from considerable government support and investment in higher education, Singapore was seen as "*a country with a history of having to innovate*" where universities offered a unique "*willingness to collaborate with others in a forward-thinking way*".

3.3. Feedback on the top-rated institutions

Appendix D highlights selected interviewee feedback on the top nine universities most frequently cited as 'emerging leaders' in engineering education (see Figure 4):

- Singapore University of Technology and Design (SUTD)
- Olin College of Engineering
- University College London
- Pontifical Catholic University of Chile (PUC)
- Iron Range Engineering
- National University of Singapore (NUS)
- Delft University of Technology
- Charles Sturt University
- Tsinghua University

Like Appendix C, while the summaries reflect the balance of views expressed by interviewees, critical feedback has been excluded in this version of the report.

4. How should quality in engineering education be measured?

The interviews explored the thought-leaders' views on how quality and impact in engineering education should be measured. They were asked to consider the criteria underpinning their selections of 'current leaders' and 'emerging leaders' and to note those institutions taking a robust approach to measuring the impact and quality of their undergraduate programmes.

There was a clear consensus that "*measuring the impact we have on our students, how much they are actually learning, is something that we as a community do very badly*". Indeed, the vast majority (over 80%) were unable to provide the name of one or more institution that they believed to have taken "*an effective approach to measuring the impact of their programmes on student learning and/or measuring the impact of an educational change*" (see question 6 in Appendix B). Instead, interviewees spoke about the paucity of reliable and comparable data by which the quality of an institution's education could be assessed, an issue that both constrained their ability to make informed assessments of the quality of an institution's education as an external observer and restricted the evidence-base upon which the engineering education community as a whole was able to move forward.

International university rankings were widely recognised to provide very poor indicators of educational quality, often relying on proxy measures such as staff-to-student ratios and graduate employment profiles. In turn, scholarly activities in engineering education were widely regarded to be insufficiently related to overall programme quality and impact: "*the scholarly work going on in engineering education is not translated back into the lecture room, it's always theoretical*". Similarly, while "*we now have these massive theoretical powerhouses [in engineering education], when it comes to influencing their own departments, they have a very hard time doing it, even themselves*".

One institution was repeatedly cited as an exception to this pattern: Aalborg University in Denmark. It was singled out as having taken a more coherent and robust approach to measuring its institutional impact on student learning. Indeed, interview feedback suggested that the systematic approach to assessing programme impacts, the demonstrable quality of the programmes and the external visibility given to the university's achievements all played a role in Aalborg University's identification as a 'current leader' in engineering education (see Figure 2). For example, in 2004, Aalborg University published a survey which captured employers' perspectives of the skills and capabilities of Aalborg University graduates compared to graduates from peer Danish institutions that had not widely adopted a problem-based approach.[14] While all graduates were rated equally for their technical engineering knowledge, Aalborg University graduates were identified as demonstrating a superior range of personal and professional skills when compared to graduates from peer institutions. More recently, Aalborg University has developed the PROCEED-2-WORK study, capturing longitudinal data from the engineering student cohort that enrolled in Danish universities in 2010, tracking their experiences and perspectives through into the workplace.[15]

Interviewees noted other institutions and projects that were seen to be taking robust approaches to evaluating student learning/development or the impact of their educational reforms. These included Penn State University, which is tracking the use of evidence-based educational practice across their engineering school,[16] the Technical University of Denmark (DTU), where graduate surveys are being used to evaluate the impact of adopting CDIO across the curriculum, and the APPLES project,[17] a four-year longitudinal study that tracked the experiences of engineering students across 21 US engineering schools.

Overall, the thought-leaders identified three broad types of informal indicators that they might use to determine the educational quality of institutions outside their own. These are summarised in the box and discussed in the sub-sections below.

Informal indicators of quality in engineering education:

1. the quality and impact of the university's graduates, such as their employability, career progression or impact on society/industry;
2. the 'delta' added to the students during their studies, by considering the student learning or 'value added' over the duration of the degree programme;
3. the institution's capacity to deliver a world-class education, as evidenced by its: (i) institutional commitment to education, (ii) educational culture, and (iii) influence on practice elsewhere.

Most interviewees touched upon all three indicators during their interview. However, one indicator – an institution's capacity to deliver a world-class education, indicator 3 above – was given particular weight and was consistently cited when identifying 'current leaders' and 'emerging leaders'. The thought-leaders noted that institutional capacity was the only indicator where the evidence was readily available (unlike 'value added' data, indicator 2)

[14] Kjærsdam, F. (2004). Technology transfer in a globalised world: transferring between university and industry through cooperation and education. *World Transactions on Engineering and Technology Education, 3*(1), 63–66

[15] PROCEED-2-WORK, Aalborg University (http://vbn.aau.dk/en/projects/proceed2work(12da3a74-9831-4e8d-9d52-27200206a6b6).html)

[16] Zappe, S. E. et al (2016) Development and Implementation of Quantitative Methods to Study Instructional Practices in Engineering Programs. International Journal of Engineering Education, *32*(5), 1942-1959

[17] Academic Pathways of People Learning Engineering (APPLES) (http://www.engr.washington.edu/caee/CAEE-TR-10-01%20APPLES%20v2.pdf)

and not distorted by the quality of the student intake (unlike indicators relating to the quality and impact of graduates, indicator 1).

Feedback relating to each of the three groups of indicators is explored further in the subsections below.

4.1. The quality and impact of university graduates

The career trajectory and impact of gradates was regarded as an important indicator of the quality of an undergraduate programme. Measures proposed included:

- "*their impact on the social and economic situation of their own country*";
- the extent to which graduates "*have the capabilities that industry needs now and in the future*";
- graduates' "*career prospects ten years out*".

Simplified versions of such metrics, including graduate employability and earnings, are often included in national university rankings, and were seen to enable external observers to distinguish between the quality of peer institutions.

However, scepticism was expressed about the validity of such metrics for cross-institutional comparisons when seeking to identify the best programmes worldwide. Scepticism stemmed from the influence of the quality of the student intake on graduate outcomes. Some thought-leaders argued that the use of these 'output measures', both formally and informally, had secured a reputation of educational quality for many of the world's top-rated research universities – ones that receive an exceptional quality of student intake – that was not borne out in practice. As one interviewee observed:

> *"is the graduate [from such institutions] coming out distinctive because of who the graduate was when they came into the institution, or is the graduate coming out distinctive because of the transformation that the institution helps them to achieve while they were there?... We don't know because we have no instruments to look seriously at that question".*

Another simply commented, "*it is not clear if the 'elite' universities are playing a bigger role than just taking the cream from the top*". It was suggested that measures of 'output quality' may have been appropriate in an era where there was little differentiation in the engineering education market – "*where the curriculum in most engineering schools was roughly the same*" – and where there was limited visibility of educational practice and priorities at institutions beyond your own. However, interviewees noted that the engineering education landscape had changed dramatically in the past five years, with the emergence and increased visibility of cutting-edge education practice from outside of the top-ranked research universities. As one interviewee commented:

> *"The next generation of [leading universities in engineering education] won't be just the places that take the best students – and do whatever they like with them because, let's face it, they were always going to be good – they are also going to be the places that might be lower down in the research rankings, may not have exceptional students, but are really doing something quite special …with the students they have. Those are the places that people want to find out about, because they are doing the real trick!"*

In this context, interviewees noted their interest in institutions – such as Aalborg University in Denmark, CSU in Australia and Iron Range Engineering in the US – that were understood to be catering to "*a more typical type of engineering student*". For example, one interviewee explained that his selection of CSU as an 'emerging leader' was influenced by the fact that "*their entry cohort are not those deemed as having the greatest skills. If you are looking for intrinsic motivation when you are talking about MIT, it is straightforward, because people who go to MIT have those qualities already. But Charles Sturt are [seeking to develop] intrinsic motivation… in the people that walk through the door, people that don't necessarily have any at the start*".

4.2. The 'delta' of student learning provided by the university

Many interviewees suggested that "*the gold standard*" for measuring the quality and impact of engineering education programmes was to capture the 'delta' or 'value added' to the students during the course of their studies. These views were informed by the wider debate on 'value added' measures in higher education.[18,19,20]

However, it was widely acknowledged that "*we just don't have anything like the quality and breadth of data that we need to make any objective assessments of the 'delta' in engineering programmes. This is the next big frontier for engineering education*". Another noted that 'value added' impact measures "*are the big missing link in higher education, because to do such a thing, you need a steady hand and you need to collect a base line and you need a*

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[18] McGrath, C. H., Guerin, B., Harte, E., Frearson, M., & Manville, C. (2015). Learning gain in higher education, RAND Corporation (http://www.rand.org/pubs/research_reports/RR996.html)

[19] AASCU. (Spring 2006). Value-added Assessment. *Perspectives.* Washington, DC: American Association of State Colleges and Universities. (http://www.aascu.org/uploadedFiles/AASCU/Content/Root/PolicyAndAdvocacy/PolicyPublications/06_perspectives(1).pdf)

[20] Nusche, D. (2008), *Assessment of Learning Outcomes in Higher Education: A Comparative Review of Selected Practices*, OECD Education Working Papers No. 15, OECD Publishing (*http://www.oecd-ilibrary.org/education/assessment-of-learning-outcomes-in-higher-education_244257272573*)

continuity of the data collected. The question is, who is going to do such a thing in engineering education?"

4.3. The institution's capacity to deliver a world-class education

The capacity of an institution to deliver a world-class education was identified by almost 90% of thought-leaders as guiding their selection of 'current leaders' and 'emerging leaders'. As noted above, this was in part due to the absence of other reliable and robust data relating to educational quality.

Three dimensions of institutional capacity were given particular emphasis:

- the institutional leadership/commitment to education;
- the educational culture;
- the capacity of the institution to influence practice elsewhere.

These dimensions are discussed below. The sub-sections should be read alongside feedback relating to the educational approach of the 'current leaders' and 'emerging leaders' (see Sections 2, 3 and 6).

4.3.1. Institutional leadership in and commitment to education

Institutional commitment and leadership were identified as cornerstones of a university's capacity to provide a world-class education. Many interviewees reflected upon the institutional features that could be seen as indicators of an institutional commitment to education. These included:

- investment in learning spaces that support and progress student-centred pedagogical approaches. Examples repeatedly cited by interviewees included the investments in 'Engineering Practice Centres' in Tsinghua University (China) and the new flexible classroom spaces at DTU (Denmark);
- processes for supporting, informing and recognising teaching excellence, such as the quality and pervasiveness of faculty training in education or the extent to which education is recognised in faculty progression. Chalmers University of Technology, TU Delft and NUS were repeatedly noted for their strength in this regard.

Many interviewees also spoke at length about what was understood to be "*a direct connection between the vision and ambition of a small number of individuals*" in leadership positions and the capacity of the university to develop and maintain world-class engineering education. At a time of significant worldwide change in engineering education, such leadership was regarded as crucial. As one interviewee commented:

> "*I am getting encouraging messages from across the world – the idea that something needs to change [in engineering education] is taking hold. There is still a slight fear, but the prerequisite for change is becoming universal. But it takes a leader to do it – not many people are that brave and that charismatic*".

As this implies, many also noted that a university's prominence as a world leader was often closely tied to the continued tenure of one or two change champions: "*institutions don't cause change, it is people… for any institution, if two or three key people were to leave, the university might continue to do what it is doing, but they would not continue to move forward*". Indeed, the success of many of the 'current leaders' and 'emerging leaders' was repeatedly attributed to the calibre of specific leaders: examples included Stanford University, Charles Sturt University, DTU, TU Delft, Chalmers University of Technology, PUC and UCL.

4.3.2. Educational culture

When identifying an institution as a 'current leader' or 'emerging leader', interviewees often spoke about the university's "*unique culture in teaching*". Three elements of this culture were repeatedly emphasised:

- ***Innovative and forward-thinking approach***: "*the willingness [of the school/university] to innovate and try new things*". Many noted that a pervasive culture of educational innovation was required at both faculty and institutional level: a faculty that are "*prepared to take risks in their teaching*" and a university management that "*are willing and able to change the rules and regulations accordingly*". Institutions repeatedly highlighted in this regard were Arizona State University, Charles Sturt University, Olin College of Engineering, UCL, PUC and Iron Range Engineering.
- ***Faculty attitudes towards education***: the extent to which engineering faculty are "*informed, engaged and actively discussing teaching with colleagues*". A culture where a critical mass of faculty were "*enthusiastic and knowledgeable about engineering education*" was repeatedly identified at institutions such as Olin College, TU Delft and Chalmers University of Technology.
- ***Evidence-based approach***: the extent to which the undergraduate engineering programme was "*built on educational scholarship, not just doing what they think seems like a good direction*" and driven forward by "*an evidence-based examination of what is working and what is not*" and by "*responding to valid critique*". Institutions such as Purdue University, Aalborg University and the University of Technology Malaysia were consistently singled out as taking an evidence-based approach to their educational provision and practice.

4.3.3. The capacity of the institution to influence practice elsewhere

The majority (78%) of interviewees cited the capacity to influence practice elsewhere as a key factor in their section of ‘current leaders’ and ‘emerging leaders’. Two elements were particularly highlighted: (i) the university’s active interventions to inform, influence and improve educational practice at a regional and global level, and (ii) the transferability of the institution’s ideas and practices to other universities across the world. Each element is discussed in turn below.

Firstly, an institution’s “*outward-looking culture and commitment to external engagement*” in engineering education was seen as a key marker of current and future leadership in the field. A number of institutions were repeatedly highlighted in this regard (see box below).

Institutions engaged in activities to influence educational practice elsewhere:

- Tsinghua University for its emerging role in informing and supporting educational reform in engineering schools across China;
- Stanford University, Olin College of Engineering and MIT for formal and informal university partnerships and outreach activities that have influenced practice in engineering education across the world;
- Aalborg University and Purdue University for a quality of educational research in engineering that has informed and inspired reform elsewhere;
- Institutions such as NUS, NTU and PUC that have taken an “*open-minded and inclusive attitude towards international [university] partnerships*” to support the delivery of globally-focused student projects and opportunities.

Secondly, an approach to engineering education that was “*scalable, transferable and a role model to other programmes*” was regarded by some as an important foundation of international leadership. While noting that “*there should always be a place [amongst the world’s leading institutions] for boutique programmes, where you can incubate new ideas*”, many interviewees suggested that “*world class, to me, means that the university is responding to the issues that other engineering programmes are faced with and they are doing something about it. This means that they are operating at scale, with a diverse student [cohort] and with a tight budget*”. Many concluded that a position as global leader in engineering education should favour institutions whose conditions – student profile, resourcing and cohort size – reflected the ‘norm’ worldwide, thus allowing their ideas and practices to be portable elsewhere. For this reason, many thought-leaders were particularly interested in PUC, UCL, Arizona State University, Purdue University and Aalborg University.

5. Challenges to the global progress of engineering education

The thought-leaders were asked about the key challenges facing the development of engineering education worldwide in the coming decades. Four issues were consistently identified:

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

These issues are discussed in turn below.

5.1. Disciplinary and educational siloes

The discipline/department-based structure of many engineering schools and universities was seen to be constraining innovation and excellence in engineering education. As discussed further in Section 6, multi-disciplinary learning and increased student choice were predicted to be key features of the best engineering programmes over the coming decades. It was acknowledged, however, that such developments would be constrained by the structural separations that often exist between and beyond engineering disciplines and the lack of informal interaction across these boundaries, particularly in teaching and learning. Interviewees also noted the difficulty in reforming the 'fundamental' courses that are often "*bought in from the [university's] science school*", and ensuring that their approach, content and focus formed a coherent and consistent part of the engineering degree programme as a whole. As one explained:

> "*if a department equals a programme, there is no way that you can discontinue a programme…. [Instead] you need to create a strong power base around the [cross-disciplinary] programmes, so that departments are not only interested to offer their own standard courses, so that you are not coming with your hat in your hand begging the maths department to change anything*".

In this respect, Chalmers University of Technology in Sweden was noted by a number of interviewees to be "*a real beacon for their interdisciplinary programmes… they have created* *a good power balance [between the departments and the programmes] with mutual commitment from both sides*".

Many of the high-profile engineering and technology universities established in recent years (such as Skoltech[21] in Russia, SUTD in Singapore and Olin College of Engineering in the US) have been created without traditional engineering disciplinary boundary distinctions. Feedback from representatives from these institutions suggests that this approach has "*meant that we could focus on what capabilities we wanted for our graduates, what types of experiences we wanted them to have, rather than arbitrarily bounding them by a set of disciplines that are no longer relevant to the types of problems that they will need to solve in their careers*".

5.2. Faculty engagement with and university rewards for education

Over 70% of the thought-leaders pointed to the lack of faculty engagement and recognition as a major barrier to the progress of engineering education globally: "*the biggest impediment to change are the faculty*". Some spoke about "*the disconnect between the academic and the world of [engineering] practice"* as well as the lack of formal and informal support available to faculty to reflect upon and improve their teaching practice. However, the major focus of interviewee feedback was on "*the reluctance of faculty to change because they are in an environment where education is not rewarded by their university*". In particular, the criteria by which faculty are appointed and promoted were repeatedly cited as a major inhibitor to educational excellence and capacity to reform:

> "*Most engineering programmes are at research-led institutions. [Faculty] are ultimately being judged on being an excellent researcher… tenure is based on research, so you do enough teaching to tick the teaching box. [Educational] reform is focused on teaching people to teach more efficiently so that you can spend more time on research*".

As another interviewee put it, "*the relative thresholds for being an adequate teacher and an adequate researcher are very different*". It was also suggested that the lack of appropriate metrics for evaluating the quality and impact of teaching was an important barrier to improving its reward and recognition in faculty careers:

> "*I have great ways to measure a great researcher. I don't have the same indicators that someone is a great teacher. This makes it very difficult to endorse them for [promotion] and all we have to give them is a teaching prize*".

[21] Skoltech (http://www.skoltech.ru/en/)

Many noted that the greater weight given to research over teaching in faculty promotion reflected perceptions more broadly across higher education: "*what determines reputation [of a university] continues to be research. Unless this changes, it is difficult to see how there will be an extensive change to teaching across the [sector]… it will continue to be the outliers, the mavericks*".

5.3. Adapting to larger and more diverse student cohorts

The thought-leaders, particularly those based at large public universities, spoke about increasing student cohort sizes in engineering, and the challenges that this poses to educational quality. The views of this interviewee were typical of many:

> *"How do we deal with this expansion [of student numbers]? How do we still engage students early on with the world of engineering? How do we show them the messiness of engineering, the political and social aspects? ... How do we do this beyond the capstone project? This type of education, the type of education we want to have, is expensive. So how do you do this for all students, large cohorts of students, without compromising on everything?"*

Interviewees from institutions experiencing a rapid increase in student numbers were particularly aware that there were few 'role model' institutions delivering high-quality student-centred education at scale. In consequence, some suggested that, "*we are scrambling to respond*". It was also recognised that increasing student numbers would inevitably bring a greater diversity in student demographics and background. Although it was noted by many that "*we cannot continue to cater to the same type of students, we need to attract the students that would not normally think of engineering*", it was also suggested that a more diverse student body was not well served by current engineering curricula.

Many of the engineering schools and universities identified as 'current leaders' and 'emerging leaders' have, in recent years, established interventions specifically aimed at increasing the diversity of their student populations. Some of these interventions have involved adapting the entry criteria to undergraduate programmes. For example, CSU Engineering and the Department of Civil, Environmental and Geomatic Engineering at UCL do not require prospective students to have studied mathematics and physics as prerequisites for entry, as is typical for most engineering degree programmes, but rather have a selection process open to candidates from all disciplinary backgrounds. In addition, Olin College of Engineering uses residential 'selection weekends' to short-list potential candidates and PUC has developed a dedicated *Talent and Inclusion* entry route for under-represented groups, with dedicated mentoring and support offered to this group of students throughout their studies. It is also interesting to note that a number of the institutions identified as ‘emerging leaders’ in engineering education, such as CSU and Olin College, have achieved gender parity across their cohorts, while others, such as PUC, have seen significant increases in female participation in recent years.

5.4. Alignment of goals between government and higher education

The thought-leaders noted that government funding, support and interventions are likely to play an important role in driving change in engineering education in the coming years. They pointed to the growing number of national governments – such as Chile, the Netherlands, Singapore, Korea and China – that were strategically investing in engineering education as an incubator for a new generation of talent in technology innovation and a springboard for economic growth. While many reported that such investments are having “*a transformative effect*” on the capacity for “*visionary and ambitious reform in engineering education*”, some concerns were also expressed. These concerns typically related to the challenges faced by interviewees within their own national contexts and the perceived conflict between universities and government agencies in their priorities for engineering education. As outlined below, concerns typically fell within three broad categories.

The **first** set of concerns related to a perceived tension between “*what engineering science professors want to teach engineers to do, so that they can become young scientists and PhD students, and the needs of government and society, which is to create engineers to contribute to economic development and growth*”. Some commented that this tension “*will either progress or be resolved in the next decade*”. Nevertheless, interviewees suggested that such a conflict – and a broader lack of consensus about the purpose of engineering undergraduate education – lies at the heart of why many faculty and engineering schools are reluctant to engage in curriculum reform.

Secondly, some interviewees highlighted the restrictions imposed by national accreditation requirements, the “*expectations of local governing bodies*” and government higher education regulations. The impact of these restrictions on the structure, content and delivery of undergraduate programmes was particularly noted in countries such as China, India, Brazil and Canada; in consequence, they “*leave little room for experimentation and new ideas*”. For example, one interviewee spoke about the challenges of creating cross-disciplinary engineering programmes within an accreditation system that was intrinsically mono-disciplinary in approach: “*when you try to be innovative, try to work in a cross-disciplinary way, you see the long arm of the professional accreditation societies that prevent engineering schools from doing this*”.

Thirdly, concerns were raised about the unpredictable nature of government higher education funding, which “*makes it difficult to plan for the future”* and often “*derails or* *restricts what it is possible for [engineering] schools to do in practice*". For example, some US-based interviewees expressed concern about the reductions in state funding for public universities "*while at the same time increasing expectations for the number of graduates we can produce… expectations of access to an affordable education but without a solid economic basis for how that happens. This commodification works against innovation and is a real concern for the future. The large public universities are the places that really interesting things can happen [in engineering education] at scale, but finances will play a role*".

Other interviewees highlighted countries such as the UK and Australia, where recent changes in government policy had the potential to restrict educational innovation and the establishment of regional networks of support. For example, interviewees pointed to the recent decision of the Australian Government to cease distributing grants to support innovation in university education through the *Office for Learning and Teaching*. One interviewee suggested that, over many years, these grants "*have impacted almost every one of the 35 [engineering school in Australia]. The amount was trivial – around $8m AUS – but they would have been matched by the university and they have been very influential... We have already lost momentum*". Concerns were expressed that the strong national network of support and expertise in engineering education that has developed in recent decades across Australia may "*start to fade*" as the lack of educational grant opportunities constrains the pool of new engineering faculty willing to specialise in teaching and learning.

6. The future direction of engineering education

This section focuses on the anticipated trajectory of the world's leading engineering education programmes in the decades to come, drawing on exemplars from the 'emerging leaders' to illustrate these features.

The thought-leaders pointed to four key features that were likely to distinguish the world's best programmes of engineering education in the coming decade:

- the combination of digital technology and active learning to deliver a world-class, student-centred education to large cohort sizes;
- the increase in flexibility, choice and diversification offered to students in their engineering studies;
- curricula that bring together the themes of cross-disciplinary learning, global experience and the use of engineering to drive positive societal change;
- ensuring that key learning experiences, such as work-based learning and user-centred design projects, are not 'bolt-on' activities but allow students to reflect upon, contextualise and build upon their learning across the rest of the curriculum.

The sub-sections below explore these features in turn. In addition to feedback from the 50 thought-leaders, the report draws on the wider literature and separate consultations with representatives from the institutions highlighted.

6.1. Delivery of authentic, active learning to large student cohorts

Thought-leaders reflected upon the worldwide trend towards the integration of active, student-centred learning into engineering curricula and the benefits that this brings to student learning. It was noted that "*early pioneers like Aalborg have been an inspiration to many*" since their establishment of a new problem-based engineering curriculum in 1974.[22] The widespread influence of the CDIO initiative[3] was also noted to have "*spurred a lot of changes in a lot of countries across the world: new introductory engineering courses, industry-linked projects and learning through doing*". The interview feedback made clear that the majority of thought-leaders anticipated that "*team-based, hands-on student learning that responds to the needs of society and industry*" would underpin the world's leading engineering programmes in the decades to come. However, echoing a theme highlighted in Section 5, concerns were repeatedly expressed about the capacity of large, publicly-funded institutions to deliver such educational programmes to large student cohorts, under constrained budgets. Indeed, many

[22] Problem-Based Learning at Aalborg University (http://www.en.aau.dk/about-aau/aalborg-model-problem-based-learning/)

of the educational features common to the ‘current leaders’ and ‘emerging leaders’ in engineering education – including entrepreneurial, design or authentic industry experiences – are, in practice, only available to relatively small student cohorts (see box below).

Examples of small student cohort sizes associated with leading programmes

The National University of Singapore (NUS) and Delft University of Technology were singled out by many for the quality and influence of their programmes in engineering design education. However, these engineering design experiences can only be accessed by a minority of engineering students: the *Innovative and Design-Centric Programme* at NUS is an invitation-only programme that caters to 100 students per year-group (representing less than 10% of the engineering student cohort) and the widely-recognised design engineering experiences at the Delft University of Technology were reported to be largely confined to a single department: the Department of Industrial Design.

Although design is infused throughout the curriculum at both Olin College and the Singapore University of Technology and Design, both of these programmes were reported to operate under atypical conditions, within a relatively generous funding environment and small student cohorts.

As one interviewee commented, “*the next phase in the evolution of engineering education is for the rest of us to figure out how we can offer this type of quality of education at scale*”. In a similar vein, another interviewee noted, “*places like Olin and Iron Range are early development models – high cost, low volume – but the economically feasible version will come next*”.

It was anticipated that such a development would be realised through a blend of off-campus personalised online learning and on-campus hands-on experiential learning. It was suggested by some that “*most of the [engineering] fundamentals will be learnt online*” with “*a greater sharing of materials between universities”* to reduce costs. Two institutions – MIT and TU Delft – were singled out for the quality of their online learning provisions. However, more broadly, many interviewees noted that “*online learning is still a jungle – we have a long way to go before we have the type of individualised [online] learning that we need, but the potential is there*”. Many spoke, in particular, about the challenge of creating “*individualised pathways for each student, using the digital element to tailor learning for each student. But I haven’t seen this done, anywhere*”. Indeed, most interviewees were unable to point to any institution that demonstrated good practice in engineering online learning. The feedback from this interviewee was typical of many: “*online learning is everywhere, but none of it is particularly exceptional. It is all one-way communication, little more than videotaped lectures and online course notes*”.

Despite doubts expressed about current online tools, a number of institutions are already moving forward with a non-traditional educational model that blends off-campus online learning with intensive on-campus active learning experiences, on the assumption that “*the technology will very quickly catch up with us*”. As two interviewees observed:

> "*this is the future of the field, where you put the student at the centre and use the resources to facilitate team projects and authentic experiences, and then put the taught curriculum online*";
>
> "*these new players are going to change the landscape. With an online component and a unique model, they will be a disruptive force that will cause the whole landscape of engineering education to change. I didn't feel that way five years ago*".

Examples noted by the thought-leaders are summarised in the box below.

Highlighted programmes that blend online and on-campus learning:

- **Charles Sturt University (CSU), Australia**: in the words of one interviewee, this programme "*is the most aggressive thing I have seen. It is a new stick in the ground*". Indeed, amongst the thought-leaders that cited CSU as an 'emerging leader' in engineering education globally, almost all spoke about their particular interest in the potential transferability of its approach to their own institutions. The majority of CSU Engineering's five-and-a-half year programme is taught remotely, through online learning, while students engage in four paid year-long work placements. The students' time on campus is dedicated to intensive high-impact team-based project work, which is conducted in "*a professional, work-like environment*".
- **Iron Range Engineering (IRE), US:** while the engineering school at CSU was developed from a blank slate, IRE is an example of an engineering programme that is adapting its curricula to embrace blended online and on-campus learning. IRE was highlighted as an 'emerging leader' in engineering education for its problem-based, hands-on approach, which was described as "*a truly innovative programme and an amazing thing to watch*". The second generation of IRE is currently under development and will launch in 2018. It will be designed as a "*low cost model which will cost less than tuition*". To be established as a four-year bachelor degree programme, Iron Range Version 2 will admit 125 students per year in its steady state, a significant increase from its current intake of 25. Rather than bringing industry-sponsored projects to the students on-site, the new programme will embed students in industry to work on dedicated, authentic projects. A significant proportion of the learning and support will be supplied online.
- **New Boston-based institution, US:** a number of thought-leaders spoke about the new Boston-based university currently under development by Christine Ortiz, former Dean of Graduate Education at MIT. It was understood to be "*creating a personalised online learning strategy that will flip the entire curriculum and focus on project work for the face-to-face part*".
- **Aalborg University, Denmark:** the university is investing over nine million Danish Krone over the next three years to develop "*new models of problem-based learning for the digital age*" with a view to implementing such approaches at the university. The model is likely to bring a mixed method approaches to problem-based learning that will be supported by virtual projects, international linkages and online learning.

It should be noted that there was not a universal consensus amongst the thought-leaders about the additional benefits of online learning, above and beyond its potential economic advantages. While the majority noted that the rapid developments in online technology will soon lead to "*individually-tailored learning that far exceeds what you could ever hope for in a classroom*", some suggested that "*online learning will always be a poor substitute for the on-campus experience because it will never offer creative mentorship*".

6.2. Increase in flexibility, choice and diversification

Most thought-leaders anticipated that flexibility, choice and diversification would become increasingly prominent features of the best engineering programmes worldwide in the coming decades. Many suggested that, as "*engineering schools start to move away from seeing engineering students only as scientists, future PhD students*", a range of different learning pathways for students will be offered "*to educate students in the profile that is more oriented to their future career*". As one interviewee put it, "*beyond the fundamental core, there are so many competing topics that we could include – entrepreneurship, service learning…., internships, research methods… – we need to allow the students to explore these things and then let them choose a pathway that suits their talents and interests*". Although a number of interviewees noted that their institution was developing plans for greater choice and flexibility in the future, few have yet started to implement this within the curriculum. Interviewees, however, pointed to universities such as the University of Melbourne and Chalmers University of Technology as institutions that offered students "*different pathways which cross boundaries*".

As noted in Section 5, a major constraint to opening up such pathways was reported to be "*impenetrable departmental silos that make it almost impossible to offer students real choices that are not completely disconnected from the rest of their curriculum*". Interviewees also expressed concerns about faculty resistance to moving away from "*a one-size-fits-all*" curriculum, as well as the challenges associated with managing and evaluating such a system. They cautioned too against offering "*total flexibility through a set of electives*". As one interviewee observed:

> "*you need to have 'profile tracks' to give some guidance on what [students'] options are, not just give them millions of electives. Otherwise the students get lost. They need closeness and guidance from the teacher*".

In addition to increasing student choice, some thought-leaders suggested that the engineering education landscape would see an increased diversification in coming years, particularly outside "*prestige brand*" universities. Some anticipated that institutions would seek to establish more distinctive and focused institutional profiles, catering to a more clearly-defined market both for prospective students and graduate employers: "*to compete, you need to know what niche you are filling*". As another interviewee commented, "*there are choices that universities are going to be making – whether they are a science/technology or an engineering/design oriented university, whether they are online or on-campus, whether it is about practice or about research*". It was recognised that such developments may be particularly evident amongst universities operating in competitive markets for prospective students. In this context, it is interesting to note that many of the institutions identified as the 'emerging leaders' of engineering education (Figure 4) would be considered to offer a 'niche' engineering education, with respect to their student intake, educational focus and/or graduate profile. Some interviewees suggested that such developments were unlikely to spread to large, research-led institutions: "*[university] rankings are a big impediment to diversification. Universities clamour for prestige and prestige comes from research. You cannot do this and be too focused*".

6.3. A multi-disciplinary, global and societally-focused approach

Many thought-leaders reflected on the distinctive curricular experiences that would be shared by the world's best engineering programmes in the future. It was noted that the curricular emphasis in areas already evident amongst many of the 'current leaders' – such as user-centred design and technology-driven entrepreneurship – would continue to be prominent features. Amongst the curricular themes that were anticipated to become <u>increasingly</u> prominent amongst the best engineering programmes, three were repeatedly identified:

- ***Multi-disciplinary learning***: interviewees noted that the ability to integrate knowledge and to work effectively across disciplines, both within and beyond engineering, is increasingly seen as a fundamental skill that all engineering graduates should possess. Examples were cited from across the world of where multi-disciplinary experiences in engineering extended across multiple year-groups, such as the Vertically Integrated Projects, based out of Georgia Tech.[23]
- ***The roles, responsibilities and ethics of engineers in society***: interviewees spoke about the key role that engineers will increasingly play in tackling many of the challenges facing society, including water scarcity, the shift to non-carbon-based industries and air pollution. The majority of interviewees anticipated that this emphasis would be reflected in engineering curricula and "*a greater focus on solving human challenges and the problems facing society*" would emerge as hallmarks of the world's best engineering programmes.

[23] Vertically Integrated Projects, Georgia Tech (http://www.vip.gatech.edu/)

- ***Global outlooks and experiences:*** it was anticipated that engineering schools would increasingly focus on the development of "*skills to be effective in a global environment*", providing students with a range of opportunities to work across nationalities and cultures. It was noted, in particular, that "*most US [engineering] schools have a long way to go on the global side. We don't give our students the kind of global exposure they need and [we] are way behind some other countries*".

The three themes listed above are distinctive features of many of the 'emerging leader' institutions and often go hand-in-hand within their curricula. Examples are provided in the box below.

Programmes that combine multi-disciplinary, human-centred and global themes:

- The new **Integrated Engineering Programme**[24] **(IEP) at University College London (UCL)** is interspersed with a series of team-based projects that draw together the full student cohort of around 700 students from across the engineering school. These large interdisciplinary projects are notable for their global, societal and ethical focus, challenging engineering students with questions such as "*how can engineering contribute to global TB (Tuberculosis) vaccines?".* For example, at the close of the second year of study, all engineering students come together to participate in *How to Change the World,*[25] a two-week intensive team-based project to devise practical solutions to real societal and environmental problems from across the world. Provided with an open-ended brief from clients such as the Red Cross, mixed student teams drawn from different disciplines are asked to consider not just their technical solution, but also the societal, environmental and public policy implications of their approach. It is interesting to note that a number of interviewees cited initiatives such as the *Engineering Exchange*[26] when pointing to "*UCL's position as one of the leading academic voices in engineering social responsibility*" and as a factor in their selection of the university as a 'current leader' or 'emerging leader'.
- The **Engineering School at the Pontifical Catholic University of Chile (PUC**) has recently implemented significant reforms to its undergraduate programmes, introducing a strong emphasis on multi-disciplinary learning with a focus on entrepreneurship, creative design and societal impact. Like UCL, engineering student cohorts at PUC are large: annual intake numbers are around 750. The Engineering School has introduced a significant number of experiences within and beyond the curriculum that seek to inform students' perspectives on the social responsibilities of engineers and offer them opportunities to work with different communities both across Chile and globally. The School also offers a number of new experiences that bring together all students from across the School. One such experience is the *Research, Innovation and Entrepreneurship*[27] course. It challenges cross-disciplinary teams of students in their third year of study to develop technology-centred solutions to key challenges facing Chile in areas such as housing, waste and heath inequalities.

[24] Integrated Engineering Programme, UCL (http://www.engineering.ucl.ac.uk/integrated-engineering/)

[25] How to Change the World, UCL (http://www.engineering.ucl.ac.uk/industry/change-world/)

[26] Engineers Exchange, UCL (http://www.engineering.ucl.ac.uk/engineering-exchange/)

[27] Research, Innovation and Entrepreneurship course, PUC (http://www.ingenieria2030.org/outcome/research-innovation-course/)

Students take a user-centred approach to tackling the challenge, and engage extensively with user groups, before designing and prototyping their solution.

- At **Olin College of Engineering** the curriculum extends across and beyond engineering, with courses drawing on fields as diverse as social science, philosophy, music and visual arts. The projects that underpin the Olin College curriculum ask students to look beyond science and technology to define and solve challenges spanning multiple disciplines, and are often anchored in issues of ethics and social responsibility. Indeed, one message that was repeatedly reinforced by interviewees was the driving focus at Olin on "*developing students that can make a difference in the world*".

6.4. Integrating and embedding key learning experiences

When discussing the pedagogies that would characterise the best engineering programmes worldwide in the decades to come, many interviewees commented that "*I don't see any brilliant new techniques down the pipe. We already have the ideas. We are rich in theory. What we will need to get better at is pulling them together*".

As discussed in Section 6.1, it was anticipated that leading engineering schools would become increasingly adept at delivering hands-on, active learning at scale, to much larger and more diverse student cohorts. Another challenge repeated raised was that of ensuring that these enriching student-led curricular experiences – such as user-centred design projects, work placements or community-based social entrepreneurship – are "*not just a 'bolt-on' activity*". Many noted that, in engineering schools across the world, the benefit of these experiences often remains unexploited because they are unconnected with other curricular experiences and students are not encouraged to reflect upon and apply what they have learnt in other areas of their degree programme. It was anticipated that the leading engineering programmes of the future would better embed and integrate experiences such as design projects and work-based learning, providing a robust platform for student self-reflection and a clear pathway for students to both contextualise and apply the knowledge and skills they have gained elsewhere in the curriculum.

Examples of such integrated experiences can be seen across many of the institutions identified as 'emerging leaders' in engineering education, including PUC, UCL and Olin College of Engineering. Another example of the integration of design projects across the curriculum can be seen at **Monterrey Tech** in Mexico, which just fell short of the top 10 of the 'emerging leader' institutions. Similar to the approach taken in the *Integrated Engineering Programme* at UCL, Monterrey Tech's *Tec21*[28] curriculum is structured around a series of design-based challenges. Each challenge is associated with a set of 'prior

[28] Tec21, Monterrey Institute of Technology (http://modelotec21.itesm.mx/index.html)

competencies', with the onus placed on the student to develop these competencies, through self-directed research, engaging with the challenge user group and registering for modules linked to the challenge, many of which will be online. Student teams may also request specific support and information from specialist faculty, depending on "*the path they have taken with the challenge".*

Interviewees also spoke about the rapid growth in work-based learning in the engineering curriculum in recent years, with, for example, an increasing number of engineering schools now asking all students to participate in a 'co-op' experience. However, it was again noted that such experiences were rarely designed as an integrated and coherent element of the curriculum, with the effect that "*the learning is not contextualised and the student does not get the maximum benefit*" from the experience. Interviewees anticipated that the next generation of leading engineering education programmes will "*tie work-based learning to the learning outcomes of the undergraduate programme*". An example of a programme considered to have already taken a more thoughtful approach to integrating work-based learning was **CSU Engineering** in Australia. In this programme, students spend four out of the five and a half years of this programme in paid work placements, with only one day per week dedicated to study during this period. During these work-based periods, students are asked to submit weekly reflections on their learning and quarterly reviews to evaluate their progress against their goals. With a focus on mastery learning, students use an online interface to identify and master the skills and knowledge they need to progress in their work-based projects.

7. Conclusions

This study represents the first phase of a two-part enquiry. Conducted between September and November 2016, the Phase 1 study provided a rapid overview of the cutting-edge of engineering education globally and a horizon-scan of how the state-of-the-art is likely to develop in the future. It drew on interviews with 50 global thought-leaders in the field of engineering education as its primary evidence source.

The study highlighted the dominance of the US and Europe amongst the institutions identified to be 'current leaders' in engineering education, with Olin College of Engineering and MIT most frequently cited as the premier institutions. Best practice worldwide was associated with a number of educational features, including user-centred design, hands-on experiential learning and opportunities for entrepreneurial development within and beyond the curriculum. It was also noted, however, that the best practices observed amongst the 'current leader' institutions were rarely institution-wide and often confined to discrete "*pockets of excellence*".

Thought-leaders were also asked to identify the institutions that they considered to be 'emerging leaders' in engineering education; SUTD in Singapore and Olin College of Engineering were the most frequently cited. A set of features distinguished the 'emerging leaders' from the 'current leaders', and these feature are likely to mark the direction of travel for engineering education worldwide. For example, the curricula at many 'emerging leader' institutions were developed from a blank slate or were the product of a root-and-branch systemic reform. This facilitated a unified and consistent educational approach, with highly-regarded learning experiences available to all – and not a subset of – engineering students. The 'emerging leaders' were also much more likely to be drawn from Asian and South American countries, pointing to a shift in the centre of gravity of the world's leading engineering programmes from north to south and from high-income countries to the emerging economic powerhouses in Asia and South America.

Institutions most frequently cited as 'emerging leaders' also incorporated educational themes that were anticipated to characterise the best engineering programmes in the decades to come. These included (i) the blending of resource-intensive, on-campus, active learning experiences with off-campus online learning, (ii) an increased flexibility, choice and diversification offered to students, and (iii) curricula that bring together cross-disciplinary learning, human-centred engineering and global experiences.

Thought-leaders identified a number of challenges that were anticipated to constrain the progress of engineering education worldwide. These included the siloed mono-disciplinary structure of many engineering schools and universities, faculty appointment and promotion systems that were regarded as not rewarding teaching achievement and the challenge of delivering active learning to large student cohort sizes.

Taken together, the feedback from thought-leaders suggested that the engineering education sector was entering a rapid and fundamental change and one set for the emergence of new players from across the world.

Appendices

Appendix A. The experts consulted

Amon, Cristina	Dean of the Faculty of Applied Science & Engineering, University of Toronto, Canada
Andersson, Pernille	Senior Executive Educational Development Officer. LearningLab DTU, Technical University of Denmark (DTU), Denmark
Atman, Cynthia	Director, Center for Engineering Learning & Teaching and Professor, Human Centered Design & Engineering, University of Washington, US
Baillie, Caroline	Chair of Engineering Education, University of Western Australia, Australia
Besterfield-Sacre, Mary	Associate Professor and Director of the Engineering Education Research Center (EERC), University of Pittsburg, US
Bhattacharyya, Souvik	Vice Chancellor and Senior Professor, Birla Institute of Technology & Science (BITS Pilani), India
Case, Jenni	Professor of Academic Development, Centre for Research in Engineering Education, University of Cape Town, South Africa
Cha, Jianzhong	Professor and UNESCO Chair on Cooperation between Higher Engineering Education and Industries, Department of Mechanical Engineering, Beijing Jiaotong University, China
Childs, Peter	Head of the Dyson School of Design Engineering, Imperial College London, UK
Chou, Shuo-Yan	Distinguished Professor of Industrial Management and Director of the Center for Internet of Things Innovation, National Taiwan University of Science and Technology, Taiwan
Clark, Robin	Associate Dean for Learning and Teaching, School of Engineering and Applied Science, Aston University, UK
Crawley, Edward	Professor of Aeronautics and Astronautics, MIT, US
Cukierman, Uriel	IFEES President and Professor, National Technological University, Argentina
de la Llera Martin, Juan Carlos	Dean, School of Engineering, Pontifical Catholic University of Chile, Chile
Edström, Kristina	Associate Professor in Engineering Education Development, The Royal Institute of Technology (KTH), Sweden
Felder, Richard	Hoechst Celanese Professor Emeritus of Chemical Engineering, North Carolina State University, US
Fortenberry, Norman	Executive Director, American Society for Engineering Education (ASEE), US
Froyd, Jeffrey	TEES Research Professor, Dwight Look College of Engineering, Texas A&M University, US
Garza, David	Academic Vice President, Monterrey Institute of Technology and Higher Education, Mexico

Goodhew, Peter	Emeritus Professor of Engineering, School of Engineering, University of Liverpool, UK
Hadgraft, Roger	Director, Educational Innovation and Research, Associate Dean (Teaching & Learning), University of Technology Sydney, Australia
Hosoi, Anette	Associate Department Head and Professor of Mechanical Engineering, MIT, US
Jamieson, Leah	The John A. Edwardson Dean of Engineering, Purdue University, US
Kamp, Aldert	Director of Education, Aerospace Engineering, Delft University of Technology (TU Delft), Netherlands
King, Robin	Emeritus Professor, University of South Australia and Adjunct Professor, University of Technology Sydney, Australia
Kolmos, Anette	Professor in Engineering Education and PBL and Chairholder, UNESCO Chair in Problem Based Learning in Engineering Education, Aalborg University, Denmark
Koo, Benjamin	Associate Professor, Department of Industrial Engineering, Tsinghua University, China
Kozanitis, Anastassis	Professor at UQAM, University of Quebec in Montreal, Canada
Lindsay, Euan	Foundation Professor of Engineering, Charles Sturt University, Australia
Litzinger, Tom	Director, Leonhard Center for the Enhancement of Engineering Education, Penn State University, US
Magnanti, Thomas	President, Singapore University of Technology and Design (SUTD), Singapore
Malmqvist, Johan	Dean of Education, Chair Professor of Product Development, Chalmers University of Technology, Sweden
Miller, Rick	President, Olin College of Engineering, US
Mitchell, John	Vice-Dean (Education), Faculty of Engineering Sciences, University College London (UCL), UK
Mohd Yusof, Khairiyah	Professor and Director, Centre for Engineering Education, University of Technology Malaysia, Malaysia
Morell, Lueny	Principal of Lueny Morell & Associates and Director of InnovaHiED, Puerto Rico
Müller, Gerhard	Chair of Structural Mechanics, TUM Department of Civil, Geo and Environmental Engineering, Technical University of Munch, Germany
Natera, Angélica	Executive Director, Laspau, Harvard University, US
Puri, Ishwar	Dean of Engineering, Faculty of Engineering, McMaster University, Canada
Ramakrishna, Seeram	Professor and Director of Centre for NanoFibers & Nanotechnology, National University of Singapore, Singapore

Sheppard, Sheri	The Burton J. and Deedee McMurtry University Fellow in Undergraduate Education and Professor of Mechanical Engineering, Stanford University, US
Shettar, Ashok	Principal, B. V. Bhoomaraddi College of Engineering and Technology, India
Song, Sung Jin	Dean of College of Engineering and Director of Center for Innovative Engineering Education, Sungkyunkwan University, Korea
Tadesse, Tarekegn	President of Addis Ababa Science and Technology University, Ethiopia
Torero, José	Head of the School of Civil Engineering, University of Queensland, Australia
Ulseth, Ron	Director of Curriculum, Iron Range Engineering, US
Van der Veen, Jan	Chairman of 3TU Centre for Engineering Education and Associate Professor, University of Twente, Netherlands
Vedula, Krishna	Executive director, Indo Universal Collaboration for Engineering Education (IUCEE) Professor and Dean Emeritus, UMass Lowell, US
Vigild, Martin	Senior Vice President and Dean, Technical University of Denmark (DTU), Denmark
Yutronic, Jorge	Consultant on Science, Technology, Innovation and Higher Education, Chile

Appendix B. Interview questions

Provided below are the core questions used to frame each interview. All interviewees were sent questions in advance of the consultation.

1. Which 5–6 universities do you consider to be the current global leaders in engineering education, in terms of educational design, quality and influence? For each, what factors do you feel are most responsible for their success?
2. Which 5–6 universities would you consider to be emerging global leaders in engineering education, that have the potential to be at the cutting-edge of educational practice in the decades to come? For each, what impresses you most about their approach?
3. What criteria/metrics are you using to identify these global leaders?
4. How do you expect engineering education worldwide to change in the coming decade? What common features/themes do you expect to be evident amongst the world's leading engineering education programmes in 2025?
5. What do you consider to be the major challenges or barriers that will constrain the progress of engineering education reform over the coming decade?
6. Which universities, from across the world, would you consider to have taken a effective approach to measuring the impact of their programmes on student learning and/or measuring the impact of an educational reform?
7. Could you recommend any other individuals whom you feel should be consulted as part of this study?

For around half of the interviews, additional questions were included in this list. As appropriate, these additional questions were designed to (i) explore the educational vision and approach at the interviewee's own institution, and/or (ii) discuss specific topics relating to the expertise of the interviewee (such as engineering design, online learning or the measurement of educational impact).

Appendix C. Feedback on the top-rated 'current leaders'

Provided below is a summary of selected interviewee feedback on the top eight universities most frequently cited as 'current leaders' in engineering education (see Figure 2, Section 2).

- Olin College of Engineering
- MIT
- Stanford University
- Aalborg University
- Delft University of Technology (TU Delft)
- University College London (UCL)
- Purdue University
- National University of Singapore (NUS)

While the summaries generally reflect the balance of views expressed by interviewees and focus on the feedback most commonly given, critical feedback has not been included in this version of the report. For newer institutions, or those that have recently implemented a programme of educational reform, some contextual information is also included in the descriptions.

C.1 Olin College of Engineering (US)

Established in 1997, Olin College of Engineering[29] is a small private university focused on undergraduate engineering education. Its student-centred educational approach is underpinned by experiential learning, where students draw inspiration from across a wide disciplinary base to tackle design-based challenges. The themes of entrepreneurship, self-directed exploration and social responsibility are particularly evident in the educational approach. With no tenure or departments, Olin has a very unconventional culture and resource-base. The College is home to a very selective and small student cohort – annual student intake is 80, leading a number of interviewees to comment that "*Olin's reputation is disproportionate with its size*". Many noted that Olin College "*embodies everything I think we have learnt in engineering education in the past 30 years*". In this context, a number of interviewees anticipated Olin College's "*evolution from a 'boutique institution' to an institution oriented to massively support the engineering reforms throughout the world*".

[29] Olin College of Engineering (http://www.olin.edu)

Olin College was identified as a 'current leader' in engineering education by more than half of interviewees (particularly those based in North America and Europe) and an 'emerging leader' by over a quarter of interviewees (particularly those from Asia and South America). Seven individuals identified Olin College as both a 'current leader' and an 'emerging leader'.

C.2 MIT (US)

MIT[30] was widely reported to offer an "*outstanding engineering education that provides students with so many opportunities to build and integrate knowledge*" supported by "*a high exposure to cutting-edge research and researchers*". A number of interviewees suggested that "*the sheer quality of staff and students that MIT attracts means that it is a self-generating model, and one which ensures that MIT graduates are the best in the world*". In particular, many pointed to the "*array of experiences open to students to use technology in entrepreneurial ways*". MIT's influence on engineering education globally was also described by some to be "*unparalleled*", which has been further strengthened by its leadership in the CDIO[3] initiative and edX.[31]

C.3 Stanford University (US)

Stanford University[32] was identified by 40% of interviewees (and over a third of non-US interviewees) to be a 'current leader' in engineering education. The focus on design and entrepreneurship was singled out as a prominent and highly-influential feature of its approach. Indeed, it was noted that "*for the first time in Stanford's history, the majority of students are registering in engineering. This is down to the prominence of design and entrepreneurship across the campus. It has changed hearts and minds*". Interviewees consistently pointed to the "*playful, experimental quality*" of the engineering programmes at Stanford University "*that fosters freedom for the students*". Many also suggested that the engineering programmes benefitted from "*being embedded in a full-service, liberal arts university where students have experiences in humanities, learn foreign languages and can get involved in being activists*".

C.4 Aalborg University (Denmark)

From its establishment in 1974, the educational programmes at Aalborg University[33] adopted a purely PBL approach. The university was described by interviewees across the world as "*a*

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[30] MIT (http://web.mit.edu)

[31] edX (https://www.edx.org)

[32] Stanford University (https://www.stanford.edu)

[33] Aalborg University (http://www.en.aau.dk)

really mature [educational] model that is powerful and transformational. They should be on everyone's list of places to benchmark" in engineering education. Many interviewees commented on Aalborg's effective use of "*real or realistic industry problems in their projects*" and their success in "*getting students into action mode rather than transmission mode*".

A key feature of the Aalborg approach that appeared to influence its identification by interviewees as a 'current leader' or 'emerging leader' was its evidence-informed educational approach and willingness to collaborate with partners across the world. Many cited the quality of educational research from the *UNESCO Centre for Problem Based Learning*[5] – either in PBL, educational change or in programme evaluation – as a key pillar of the university's leadership and influence in engineering education.

C.5 Delft University of Technology (Netherlands)

Delft University of Technology[34] (TU Delft) was one of four institutions to feature prominently on the lists of both 'current leaders' and 'emerging leaders' in engineering education. Although its recognition in engineering education was attributed to a range of different factors, it was most notably identified by many as the European leader in both engineering design and engineering online learning. The university was also noted for its high quality learning spaces, strong links with industry and "*global, multi-disciplinary approach*" to education. In addition, the growing support for higher education from the Dutch Government was highlighted by a number of interviewees to be a contributor to TU Delft's recognition in engineering education, as was its membership of the national *4TU Centre for Engineering Education.*[35] In this context, many pointed to Delft as a "*global thought-leader in engineering education*", citing a recent publication[36] that outlines TU Delft's vision for engineering education in the future. A number of interviewees commented that the university "*gives the appearance that there is a Delft spirit and attitude, where they are forward-thinking, ambitious and entrepreneurial and committed to education. In other universities, the education is more fragmented, but at Delft they seem to pull the pieces together*". Two departments at the university, however, were consistently singled out for their educational leadership within the university: Aerospace Engineering and Industrial Design.

[34] Delft University of Technology (http://www.tudelft.nl/en/)

[35] 4TU Centre for Engineering Education, Netherlands (https://www.4tu.nl/cee/en/)

[36] Engineering Education in A Rapidly Changing World: Rethinking the Mission and Vision on Engineering Education at TU Delft (http://www.lr.tudelft.nl/fileadmin/Faculteit/LR/Nieuws_en_Agenda/Nieuws/2014/docs/visiedocument_TU_def.pdf)

C.6 University College London (UK)

In 2014, the School of Engineering at University College London[37] (UCL) implemented the *Integrated Engineering Programme*[24] (IEP), a root-and-branch reform of the undergraduate curriculum across all engineering programmes. It followed a radical and well-regarded educational reform in UCL's Department of Civil, Environmental & Geomatic Engineering. The centrepiece of this departmental curriculum change was a series of 'scenarios', operating in five-week cycles, where students spend four weeks acquiring a range of knowledge and skills that can be applied in a one-week intensive design challenge.

The new IEP curriculum has adopted similar discipline-specific 'scenarios' throughout the first and second year of the curriculum. These are complemented by a series of cross-disciplinary, team-based projects that bring together students from across the engineering school – typically around 700 in each year-group – often framed around themes in social responsibility. Multi-disciplinary learning is a significant focus of the IEP curriculum, which has introduced a requirement for all engineering students to take a minor. The eighteen minor pathways offered are predominantly cross-disciplinary in nature, and include subjects such as *Engineering and Public Policy*, *Tech Journalism*, *Sustainable Building Design* and *Connected Systems*. The IEP has also streamlined some of the 'core' engineering teaching across the School. For example, *Mathematical Analysis and Modelling* had previously been taught separately by each department, with some delivering the subject 'in house' and others outsourcing the course to the mathematics department. Through the IEP, a common mathematics curriculum was agreed across all departments, with the new course taught by an inter-disciplinary teaching team to all engineering students and supported by discipline-specific tutorials with each department.

Many interviewees commented on the significance of "*a university like UCL*" implementing such an ambitious educational reform. As one interviewee put it, "*…they are a massively research-intensive university, one of the top ten in the world, that could have really laughed this off. But they didn't. They are taking the undergraduate education seriously*".

C.7 Purdue University (US)

A number of factors appeared to support Purdue University's[38] identification as a 'current leader' in engineering education. Some cited the "*quality of the first year programmes*" that are delivered by the School of Engineering Education, as well as the EPICS[39] programme

[37] University College London (https://www.ucl.ac.uk)

[38] Purdue University (http://www.purdue.edu)

[39] EPICS, Purdue University (https://engineering.purdue.edu/EPICS)

that was reported to have had significant influence on engineering undergraduate programmes across the world. Other interviewees pointed to Purdue's leadership in "*figuring how you can do hands-on learning at scale*". For example, all of Purdue's 2000 engineering students "*will have had a substantial experiential experience in their four years – like internships, coops, extended service learning, undergraduate research or study aboard – of at least one semester or more*".

Across the engineering education community, however, it is probably the School of Engineering Education[40] with which Purdue University is most strongly associated. Many noted the quality of the scholarly research conducted by the School and the influence this has had on attitudes towards and practices in engineering education both across Purdue University and the rest of the world.

C.8 National University of Singapore (Singapore)

The feature of the engineering undergraduate programme at the National University of Singapore[41] (NUS) most commonly highlighted by interviewees was the *Innovative & Design-Centric Programme*.[42] Established in 2009, this invite-only programme within the Faculty of Engineering provides hands-on opportunities for students to work on authentic, multi-disciplinary design challenges and develop entrepreneurial, creative and leadership skills.

Other aspects of NUS's engineering undergraduate programmes that were repeatedly highlighted by interviewees included their flexibility – "*there are a huge number of options and electives that students can take*" – and their "*commitment to offering their students a truly global experience… 70% of their undergraduates spend at least one semester at a university abroad*". Indeed, the openness of the university "*to engage in international collaborations*" was a topic repeatedly discussed by interviewees, as was the university's ability "*to get some of the best students and teaching staff from across the world*". The educational developments implemented across the engineering school at NUS over the past decade were described as a "*bold and impressive experiment*", in an institutional environment that "*is deeply committed to supporting quality teaching*".

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[40] School of Engineering Education, Purdue University (https://engineering.purdue.edu/ENE)

[41] National University of Singapore (http://www.nus.edu.sg)

[42] Innovative & Design-Centric Programme, NUS (http://www.eng.nus.edu.sg/edic/dcp.html)

Appendix D. Feedback on the top-rated 'emerging leaders'

Appendix D highlights selected interviewee feedback on the top nine universities most frequently cited as 'emerging leaders' in engineering education (see Figure 4):

- Singapore University of Technology and Design (SUTD)
- Olin College of Engineering
- University College London
- Pontifical Catholic University of Chile (PUC)
- Iron Range Engineering
- National University of Singapore (NUS)
- Delft University of Technology
- Charles Sturt University
- Tsinghua University

Like Appendix C, while the summaries reflect the balance of views expressed by interviewees, critical feedback has been excluded in this version of the report. Additional context information is provided for new institutions or those that have recently implemented a programme of educational reform.

D.1 Singapore University of Technology and Design (Singapore)

Singapore University of Technology and Design[43] (SUTD) was identified by more than a quarter of interviewees to be an 'emerging leader' in engineering education worldwide. The university was established in 2012 in collaboration with MIT with a mission "*to advance knowledge and nurture technically grounded leaders and innovators to serve societal needs*". SUTD offers a number of distinctive features in both its structure and educational approach. For example, the university has no departments or schools and offers students considerable opportunities for cross-disciplinary learning as well as "*a range of multi-disciplinary connections outside engineering*". Building upon "*a solid grounding in the [engineering] fundamentals*", the curriculum was described as "*emphasising experiential learning, with design built into the fabric of the courses".* Many interviewees noted that the university's design emphasis was supported by state-of-the-art maker spaces and flexible learning spaces. On completion of the degree programme, it was estimated that every SUTD student "*would experience 20 to 30 intensive design projects… that help them make connections*

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[43] Singapore University of Technology and Design (SUTD) (http://www.sutd.edu.sg)

between courses". As MIT's only major university partner in the undergraduate space, SUTD was understood by some interviewees to provide a window into how the undergraduate education programmes at MIT might evolve in the future. This feature appears to have further supported SUTD's profile and recognition across interviewees.

D.2 Olin College of Engineering

See Appendix C.

D.3 University College London (UK)

See Appendix C.

D.4 Pontifical Catholic University of Chile (Chile)

The Pontifical Catholic University of Chile[44] (PUC) is one of South America's most highly-ranked research-led institutions. In 2011, the Engineering School at PUC launched a significant programme of reform – *Clover 2030*[11]– that cuts across all of its operating functions: research, education and technology transfer. This ongoing systemic reform has been accelerated over the past two years by a major government investment in selected Chilean engineering schools, *Engineering 2030*, aiming to drive national capacity in technology innovation and entrepreneurship. Interviewees noted, in particular, the "*pioneering vision of the school… [that is] poised to become a prominent engineering leader, regionally and internationally*".

Moving away from a traditional Chilean engineering education model – that was largely teacher-centred and six years in duration – the educational pillar of the *Clover 2030* programme seeks to establish a student-centred education that emphasises multi-disciplinarity, user-centred design and social responsibility as well as student flexibility and choice. Interviewees also noted the 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 themes within and beyond the curriculum and the school has developed a concept called the 'visible and invisible curriculum', which allows students to identify and select minors, courses and extra-curricular experiences that support the development of capabilities in a variety of different entrepreneurial pathways. The school is also investing in a range of new multi-disciplinary learning spaces and maker spaces as well as a department of engineering education to provide an evidence-base for its curricular developments.

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[44] Pontifical Catholic University of Chile (PUC) (http://www.uc.cl/en)

D.5 Iron Range Engineering (US)

Catering largely to the Community College student market, Iron Range Engineering[45] (IRE) is an upper-division programme, comprising the final two years of a four-year engineering bachelor's degree. Although based on a Community College campus, IRE degrees are certificated by Minnesota State University, Mankato. The programme first opened its doors to students in 2009 and its annual intake is currently fixed at 25. The two-year programme is entirely structured around semester-long industry-sponsored projects using a PBL approach, with no traditional courses. At the start of each semester, students are expected to define their own learning goals and outcomes relating to each project as well as determine how these will be achieved. At the close of each project, students are asked to submit both a design report and a learning report. All exams are conducted orally, before a mixed panel. Self-directed learning is a critical element of IRE, which is supported by a significant focus on student self-reflection. Indeed, students are asked to document and submit around 150 structured self-reflections during the two-year programme. With a strong programme focus on "*supporting the unique trajectory of every student*", the continuous process of self-reflection also helps to guide and inform student decision making in their choice of projects, competencies, specialisms and ways of working. Professional expectations are also strongly emphasised in the IRE programme, with a dress code, a professional code of conduct relating to student and staff communication and a learning environment that "*emulates professional practice*".

A number of interviewees commented that IRE was "*a truly innovative model, based on good scholarly work, that doesn't get the press and the accolades that it deserves*". As one interviewee commented, "*they are not starting with any cream-of-the-crop students. They take students that wouldn't make it into outstanding engineering departments and they turn them into independent learners in two years…. It is really very* different".

D.6 National University of Singapore (Singapore)

See Appendix C.

D.7 Delft University of Technology (Netherlands)

See Appendix C.

[45] Iron Range Engineering (http://ire.nhed.edu)

D.8 Charles Sturt University, Australia

Established in 1989, Charles Sturt University (CSU)[12] is a regional university located in the sparsely populated eastern part of New South Wales, Australia. In response to calls to increase the regional engineering talent pool, CSU has established a new masters-level degree programme in Civil Systems Engineering from within its Faculty of Business. The first cohort of 29 students entered CSU Engineering in February 2016. Steady-state intake numbers are expected to be around 80. The stated goal of CSU Engineering is to "*train entrepreneurial engineers in a regional setting*". With no set entry criteria and an interview-based selection system, the programme seeks to establish a diverse cohort, particularly with respect to gender and ethnic background.

CSU Engineering has taken a very unconventional approach to both its structure and pedagogy. The programme is five and half years in duration: students are engaged in on-campus teaching and learning activities during first 18 months, with the remaining time structured around four paid one-year work placements in industry which are supported and assessed through online learning. The programme uses a 'mastery' approach, whereby students identify and master the subject knowledge required to complete project work and work-based tasks.

The programme's overall knowledge base is characterised as an online 'Topic Tree', of which students must master a defined proportion before graduation. With significant use of online learning, most of the face-to-face teaching is focused on project-based learning. On-campus authentic hands-on challenges are undertaken during the first 18 months of the curriculum. Students then engage with structured projects as part of their off-campus work placements, which are interspersed with residential on-campus 'scenario weeks'. Student assessment is structured around online self-reflective portfolios, which they compile and maintain throughout the degree programme to demonstrate achievement of the learning outcomes.

Noting the unique and radical approach adopted by CSU Engineering, some interviewees suggested that "*if they can pull this off, it is definitely a direction that we might be thinking to go down in the future*". With the first student cohort only one year into their studies, however, it was also noted that "*this programme is still very new, and is untested. The unique aspects of the programme – like the work-based learning – are not even in play yet*".

D.9 Tsinghua University (China)

Many of the interviewees that identified Tsinghua University as a global 'emerging leader' in engineering education commented that "*I would not have given you Tsinghua's name a few years ago – they have changed a lot in the past five years*". It was noted that the university's status as a global research powerhouse in engineering was "*starting to be balanced by their thinking about engineering education*". In particular, it was reported that Tsinghua University has taken a national leadership position to drive educational reform in engineering schools across China, as part of the government-supported programme to build "*the technology and innovation skills of the country*". Such national leadership will be further reinforced by the recent establishment of the UNESCO Centre for Engineering Education[46] that will be based at Tsinghua University.

Many interviewees, particularly those based within Asia, commented upon the bold and inclusive position that Tsinghua had taken in enabling educational reform: "*it is adventurous and it is new. Though it is a top-down change, if [faculty] come up with good ideas, they will try it. I am impressed with the kind of support that they are willing to put into different ways of teaching… and it is very well supported by the Chinese Government*". Interviewees highlighted a number of aspects of this emerging strength in engineering education. Most notable was the investment in new buildings and maker spaces, reflecting an increasingly strong focus on technology-driven entrepreneurship and innovation across and beyond the curriculum. A number of interviewees also spoke about the "*explosion of extra-curricular activities at the university*", which, for some, reflected a shift towards a more student-centred and experiential educational approach where "*some professors are allowing students to become more adventurous, helping them to be leaders, not just engineers*". As one interviewee commented, "*what inspires me most about Tsinghua is the student groups – the Innovation Club, the Entrepreneurship Club, the Flying Club – students are moving so fast and they are calling the shots. It is strong and passionate... and it is changing*".

[46] International Center for Engineering Education (http://www.unesco.org/new/en/media-services/single-view/news/unveiling_of_international_centre_for_engineering_education/)