

Snapshot review of **engineering** **education** reform in Chile

January **2017**
Dr. Ruth Graham



United Nations
Educational, Scientific and
Cultural Organization



AALBORG UNIVERSITY

Aalborg Centre for Problem Based Learning
in Engineering Science and Sustainability
under the auspices of UNESCO



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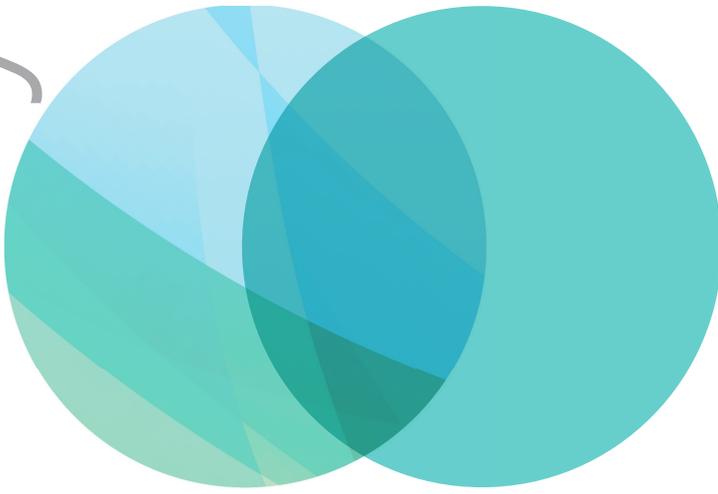
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Executive summary



This report presents the findings of a snapshot review of engineering education reform in Chile, conducted between October 2015 and June 2016. Focusing on selected engineering schools that have achieved positive and well-regarded educational change, it explores the drivers, facilitators and barriers to engineering education reform across the country. Case studies of engineering education reform from across Chile are also highlighted. The study draws on one-to-one interviews (n=36) as its primary evidence-gathering tool, targeting change leaders, senior university managers, engineering faculty, policy makers and other stakeholders supporting or observing educational change in engineering in Chile. The interview data were complemented by a snapshot literature search and review, to identify pre-existing evaluations or documentation relating to engineering education reform in Chile.

Following a brief overview of the national higher education environment, the report charts the evolution of Chilean engineering education over the past two decades. It goes on to present exemplars in engineering education, including the *Factoria* at the University of Desarrollo, *Engineering Challenges* at the Pontifical Catholic University of Chile and the project-based engineering *Workshops* at Adolfo Ibáñez University.

The study highlights the rapid progress made in Chilean engineering education in the past decade, setting it apart from international peers with respect to both the pace and scale of change. In little over ten years, the Chilean educational landscape has been transformed from one almost entirely devoted to lecture-based delivery of traditional engineering content to widespread university engagement with educational change. For a country of less than 18 million inhabitants to have over 15 engineer-

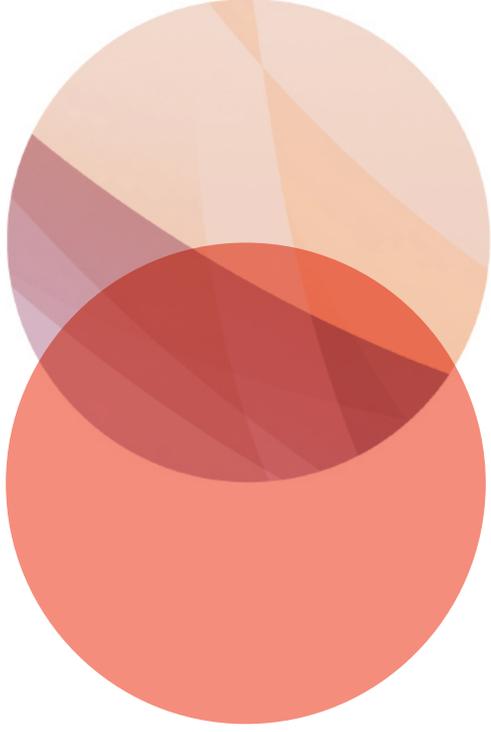
ing schools engaged in ambitious programmes of systemic curricula reform is internationally unique.

The report points to a number of factors that have underpinned this transformation. One critical factor has been the influence of two government interventions in higher education – *MECESUP* and *Engineering 2030* from the ministries of education and finance respectively – that between them have created an appetite and momentum for ambitious systemic educational change across the country. Reform has also been driven by national investment in technology innovation as a vehicle for economic growth, strong leadership from influential engineering schools across the country and the influence of networks of support and best practice from across the world.

Stakeholders recognise, however, that significant progress still needs to be made and most Chilean engineering programmes do not yet compe-

te with the best programmes across the world. The country also faces major challenges that must be addressed, including establishing stronger networks of support between universities, building the national research base in engineering education and connecting industry with the educational reform agenda. However, the central barrier that continues to constrain reform across the country is the low level of engagement by grassroots faculty. Strong leadership from both government and key university managers has stimulated change at an impressive speed. However, greater levels of faculty engagement will be essential if it is to be sustained beyond the current phase of targeted government funding in higher education. With stronger faculty engagement and continued leadership from government and key engineering schools, Chile is well-positioned to establish itself as a leading nation for engineering education in the decades to come.

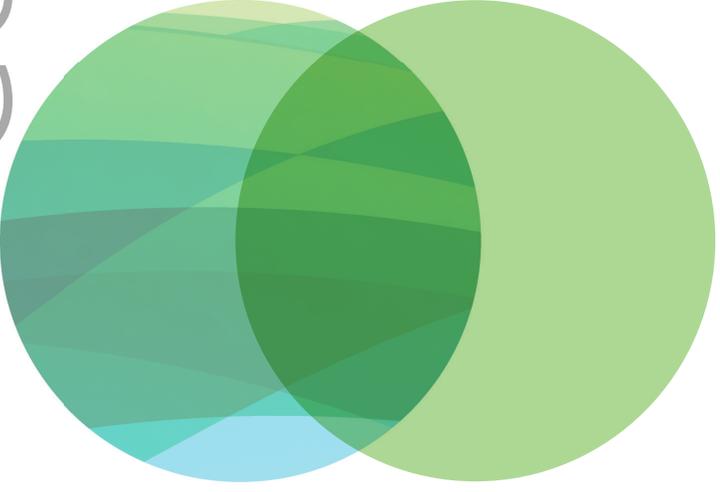
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I am particularly grateful to the Chilean engineering students, faculty, university managers, representatives from government agencies as well as national and international observers who contributed so generously to the study by giving their time and sharing their experiences, knowledge and expertise.

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Introduction



1.1. FOCUS OF THE REPORT

Many countries across the world are struggling to catalyse a momentum for systemic change in engineering education. Chile, however, appears to be bucking this trend. Anecdotal evidence suggests a national surge of curricula reform in engineering schools in recent years. It also appears that key government interventions in higher education have played an important role in establishing an academic culture which is open to educational change. Identifying the nature of and drivers for engineering education reform in Chile would provide valuable insight for the regional and international engineering education community in the design of future strategies for sector-wide change.

This summary report presents the findings of a snapshot review of engineering education innovation and reform in Chile, conducted between October 2015 and June 2016. Focusing on selected engineering schools that have successfully pursued well-regarded educational change, it addresses two central questions:

1. **What are the drivers and barriers to change?** In particular, what are the key factors driving educational change in engineering schools in Chile and what role (if any) have government interventions played in shaping the nature and ambition of the educational reforms apparent?

2. What changes are being made?

In particular, what is the focus of educational reform in Chilean engineering schools and what examples of good practice exist?

1.2. STUDY APPROACH

The snapshot study draws on one-to-one interviews as its primary evidence-gathering tool. Interviews targeted change leaders, senior university managers, engineering faculty, policy makers and other stakeholders supporting or observing educational change in engineering in Chile. The interview data were complemented by a snapshot literature search and review, to identify pre-existing evaluations or documentation relating to engineering education reform in Chile. Although not exhaustive, the literature search focused on published work in two areas of interest:

- reviews of the higher education landscape at a national and/or regional level (such as Letelier et al., 2009, Rudnick et al., 2010, OECD, 2010, Benedikter and Siepmann, 2015 and Salmi, 2013), including descriptions of government-led initiatives

aimed at reforming higher education in Chile (such as Yutronic et al., 2010, Reich, 2012);

- descriptions of educational reforms at an institutional or course level (such as Poblete et al., 2007, Loyer et al., 2011, Muñoz et al., 2013, Vega et al., 2013, Gallardo et al., 2014, Rojas et al., 2016), including, where available, institution-specific reports describing change programmes and ambitions for the future (such as from USCS¹, UC² and UoCH³).

The interview evidence was also set in the context of the wider international landscape of engineering education reform. This global perspective included the factors driving engineering education change worldwide (National Academy of Engineering, 2004, Royal Academy of Engineering, 2007, King, 2008), the global progress of engineering education reform (Lattuca et al., 2006, De Graaff & Kolmos, 2007, Crawley et al., 2007, Lucena et al., 2008, Borrego et al., 2010, Froyd et al., 2012, Jamieson, 2012), the educational approaches that impact positively on student learning in engineering (Mills & Treagust, 2003, Prince & Felder, 2006, Strobel & Van Barneveld, 2009, Bielefeldt et al.,

2009, Litzinger et al., 2011) and the author's own work on higher education reform across the world (Graham, 2009, 2012, 2014, 2015).

These supplementary sources provided important background information; however, as noted above, the key focus of the evaluations was the stakeholder interviews. Initial targets for interview were identified through the review of the literature, recommendations from agencies supporting regional and international educational reform (such as the CDIO network⁴ and LASPAU⁵) and the author's existing connections with national universities and government agencies. Further targets for interview were identified through recommendations from the individuals consulted.

All interviews were conducted remotely and in English, lasting between one and two hours. Most interviewees (64%) opted to consider the written questions in advance and two individual interviewees chose to respond to the questions in writing.

In all, 36 individuals were consulted for the study, drawn from three stakeholder groups, as illustrated in the table below. Twelve Chilean universities were represented amongst the interviewees.

1. USCS, *Curricular Renewal of the Engineering Faculty* (<http://renovacioningenieria.ucsc.cl>)

2. UC, *Engineering 2030* (<http://www.ingenieria2030.org>)

3. UoCH, *A New Engineering for 2030* (ingenieria.uchile.cl/documentos/ingenieria-2030-pdf-41-mb_106320_3.pdf)

4. CDIO – *Conceive, Design, Implement and Operate* (<http://www.cdio.org>)

5. LASPAU, *affiliated with Harvard University* (<http://www.laspau.harvard.edu>)

Stakeholder group	Number of interviewees	Quotes from the 36 interviewees consulted for this study 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. Within the case studies of good practice included in the report, a number of direct quotes from interviewees are included with the name of the speaker identified. In these cases, permission was explicitly granted from the interviewees in question prior to inclusion of the quotes. These individuals were also given the opportunity to review both the case study and their quote/s and suggest amendments as appropriate.
Senior university managers from Chilean universities and engineering schools, at the Dean and Associate Dean level	12	
Faculty, staff and students from Chilean engineering schools that are engaged with and/or leading education reforms	14	
Representatives from Chilean government agencies (such as <i>CORFO</i> and <i>MECESUP</i>) and observers from outside the country (including international educational advisors, regional development agencies and members of international educational consortia)	10	

1.3. STRUCTURE OF THE REPORT

The outcomes of the study are presented in six sections:

- **Section 2** provides an overview of the higher education environment in Chile;
- **Section 3** charts the historical development of engineering education reform across the country;
- **Section 4** presents examples of good practice in engineering education from across Chile;
- **Section 5** highlights the factors that appear to have supported successful adoption of educational reform in Chilean engineering schools;
- **Section 6** outlines the barriers that are constraining and challenging educational reform across the country;
- **Section 7** offers some concluding comments on the scale and progress of engineering educational reform in Chile.

Case studies are used throughout the report to illustrate the study outcomes and showcase examples of good practice from across the country. The case studies included in the report are listed below:

- **Case study 1.**
The MECESUP programme
- **Case study 2.**
Widening participation activities: the University of Bio Bio
- **Case study 3.**
Engineering 2030
- **Case study 4.**
Workshops: Adolfo Ibáñez University
- **Case study 5.**
Engineering Challenges: Pontifical Catholic University of Chile
- **Case study 6.**
Curricula reforms: Catholic University of the North
- **Case study 7.**
Factoria: University of Desarrollo

A list of acronyms for the Chilean universities included in this report is provided in the Appendix.

The national higher education context



The Chilean higher education landscape has changed profoundly in the past three decades. Prior to 1981, the country was home to only eight universities, all of which were publicly-funded. Following changes in government policy, a significant number of new private higher education providers were established across the country. Today, Chile is home to 60 universities, of which:

- 35 are private institutions created after 1981;
- 25 are publicly-funded state and private institutions, often referred to collectively as 'CRUCH', created from the original group of eight 'traditional' institutions and their branch campuses.

Following this expansion in higher education provision and the country's return to a democratic government in 1990 came a dramatic increase in student participation. Between 1990 and 2012, student enrolment in Chilean higher education increased fourfold to 1.1 million. According to OECD figures, 31% of Chile's younger generation will graduate with a Bachelor's degree (or equivalent) during their lifetime, compared to just 13% of the country's current working-age population (OECD, 2015). The vast majority of the growth in higher education participation has been focused in the private university sector; today over half of Chile's undergraduates are enrolled at private universities.

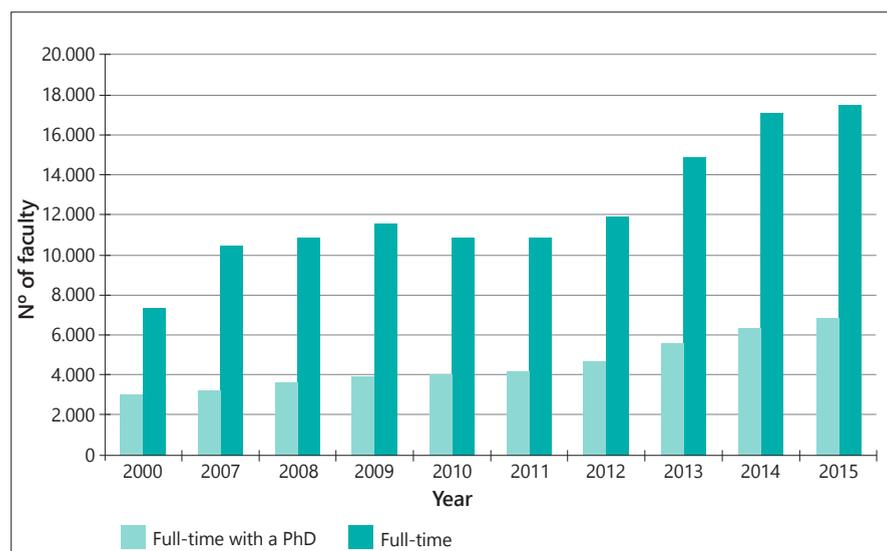
The Chilean higher education system as a whole is heavily dependent on tuition fee income, sourced from students and their families. Although national funding for higher education exceeds the OECD average – Chile spends 2.5% of its GDP on higher education compared to an OECD average of 1.6% – the majority of this funding is sourced from private expenditure: 65% of Chile's higher education budget is privately-funded, compared to an average of 30% across the rest of the OECD (OECD, 2015). The government is currently implementing major changes in higher education funding to provide tuition-free education for a significant proportion of the country's poorest students. Many of the interviewees consulted for this study noted that the impact of these reforms on educational quality and the capacity of universities to invest in educational innovation and reform

was as yet unclear. As one Associate Dean commented: *"the environment is so strange. All of the universities are focused on the government changes. They are not thinking about innovation, they are not thinking about anything. They are paralysed, waiting for the next steps of the government"*.

The late 1990s marked the beginning of a significant period of change in Chilean higher education, following the country's return to democracy in 1990. As outlined in Case Study 1, the *Higher Education Quality Improvement Program (MECESUP)*, jointly supported by the Chilean government and the World Bank, was launched in 1997, and called on universities to fundamentally reform educational programmes. As the rest of the report will make clear, this intervention was to have a far-reaching effect on the capacity for and progress of educational change in

Chilean higher education. Many interviewees noted that the late 1990s also marked the start of a transition towards *"more professionalisation in universities, the government pushed us to be more research-centred... This was a big change in terms of faculty careers"*. Prior to the turn of the century, graduate study in Chile was limited, and the few faculty qualified to PhD level typically had undertaken their studies abroad. MECESUP led a drive to increase the proportion of faculty with doctoral training. As illustrated in Figure 1, between 2000 and 2015, the proportion of PhD-qualified faculty in Chilean universities rose from 30% to 39%. At the same time, universities and faculty came under increasing pressure to improve research output and recognise research-based activities in formal promotion and recognition systems.

Figure 1
Number of full-time faculty and full-time faculty with PhD qualifications in Chilean universities, 2010-2015. Data source for 2007-2010: Information Systems of Higher Education, Chilean Ministry of Education. Data source for 2000: Institutional Financing Department, MECESUP. Note: reliable data is unavailable from 2001-2006.



Although the research output at many Chilean universities has improved considerably in recent years, two universities in particular continue to stand out for their quality and impact: the University of Chile (UoCH) and the Pontifical Catholic University of Chile (UC). These institutions are amongst a handful in Latin America that consistently feature within the top 250 of the *QS World University Rankings*.⁶ Two of the country's oldest and largest CRUCH universities, together they account for 52% of Chile's doctoral student population, 47% of ISI articles published and 60% of competitive research funding nationally (Bernasconi, 2011, Salmi, 2013). They also stand apart from their national peers in terms of the quality of their student intake. These factors may explain why many interviewees noted that the priorities and activities of these two universities have an important influence across the national higher education sector. As one professor from a regional university noted, *"if they started to do things differently, if they started to teach differently, it would have an impact on everyone"*.

6. In the *QS World University Rankings 2016-2017*, the ranking positions for UC and UoCH were 147 and 200 respectively.

CASE STUDY 1: MECESUP

In 1997, seven years after the country's return to democracy, the Chilean government launched *MECESUP* in collaboration with the World Bank. At a time of rapid increase in participation rates and student numbers, this competitive fund was designed to reverse two decades of underinvestment and improve quality and transparency across the Chilean higher education sector. As Ricardo Reich, General Coordinator of *MECESUP* between 1997 and 2013, explained, *"under the military government, the investment in higher education infrastructure stagnated for twenty years... many institutions around the country were in poor shape and the increase in [student] enrolment was putting a lot of pressure on the system for funding and quality assurance"*.

MECESUP had three key strategic objectives:

1. to drive systemic and sustainable improvements in university undergraduate education, including curriculum design, pedagogy and learning spaces;
2. to improve the quality of and participation in postgraduate study, thus improving the faculty skill-base in teaching and learning across all disciplines;
3. to improve public accountability in higher education funding.

Over a 15-year period (2000–2015), World Bank loans for *MECESUP* totalled US\$205m with an additional investment of US\$545m by the Chilean government. A three-phased approach was taken to the initiative, the government investment increasing and the World Bank loan contribution decreasing with each subsequent phase:

Phase 1. (1997 - 2004): Focused only on the CRUCH group of 'traditional' Chilean universities and vocational institutions, the first phase of *MECESUP* invested in institutional infrastructure and the establishment of training programmes for PhD candidates and support programmes for early career faculty.

Phase 2. (2005 - 2010): The second phase extended its scope beyond CRUCH institutions to include some of the new private universities that were contributing to the development of research, PhD studies and teacher training

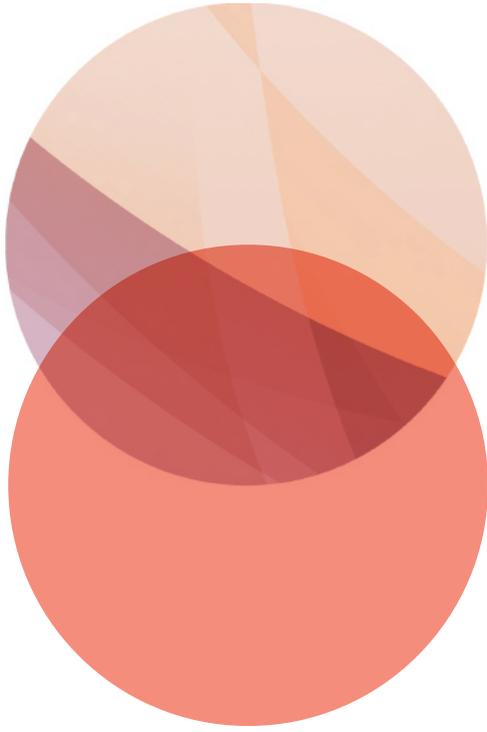
programmes. Using the Academic Innovation Fund (created during Phase 1), this phase of the initiative focused on pedagogical and curricula reform as well as professional development in teaching and learning.

Phase 3. (2012 - 2016): The final phase of *MECESUP* focuses on deeper and more rapid educational change at a smaller group of targeted universities, using what are termed 'institutional improvement plans' that are monitored against performance-based agreements.

MECESUP represented a step change in the government's approach to improving university education: as one interviewee observed, "before then, funding was allocated in an arbitrary way, with no public accountability and in small amounts". The collaboration with the World Bank played an important role in formulating a new approach. As Ricardo Reich noted: "the World Bank convinced the government to change from incremental institutional financing to competitive funding. Chile did not have a history of competitive funding in teaching and learning or in infrastructure investment....and Chilean universities were not accustomed to being asked for results that you could measure. The World Bank wanted to offer an alternative to incremental funds and to allocate funding on a competitive basis where you can introduce priorities and strategic planning". Ricardo Reich attributed much of the success of *MECESUP* to the accountable and transparent approach taken by this competitive fund, and the levels of trust it established across the higher education sector: "all the details – from the peer assessment system to the way the calls were made and the decision-making process – everything was available and transparent".

Again marking a departure from previous government interventions, *MECESUP* brought together the opportunity for significant institutional investment with relatively high levels of university freedom: although the ultimate goals for reform were stipulated by *MECESUP*, the focus of and approach to change were largely determined by the institutions themselves. In a decentralised country, with relatively high levels of autonomy at both institutional and professorial levels, this appeared to play a critical role in engaging universities and university teachers with the change agenda.

Historical development of Chilean engineering education



This section charts key stages in the progress of engineering education in Chile over the past 20 years, highlighting some of the factors that appear to have supported change:

- it begins by noting some distinctive features of the traditional Chilean engineering degree, which was built upon scientific and mathematical rigour (Section 3.1);
- the next section outlines the course-level educational reforms that emerged during the early 2000s, which were developed within an environment of increasing student participation and growing concerns about retention rates (Section 3.2);
- the move towards systemic educational change in engineering during the mid-2000s is described, reforms that were often supported by *MECESUP* funding and informed by networks of support and international good practice (Section 3.3);
- dual concerns that gained prominence from the mid-2000s onwards are noted – the length of the engineering degree and the equality of participation in higher education across Chilean engineering schools – that have each had a growing influence on the design and focus of educational reform across the country (Section 3.4);
- finally, the emergence of technology-driven entrepreneurship and innovation as a major focus

of change to Chilean engineering programmes is outlined, which has been supported by a major government programme of investment (Section 3.5).

3.1. FEATURES OF THE TRADITIONAL CHILEAN ENGINEERING DEGREE

Historically, engineering degree programmes in Chile have adopted a highly traditional, teacher-centred approach, described by one Associate Dean as *“conventional and conservative... heavily influenced by the classic European and US engineering programmes”*. Programmes were notable for their lack of active or experiential learning. The mathematical and scientific rigour of the curriculum was described as *“incredible”* and understood to be a *“point of pride”* for many faculty.

Early years of study typically focused exclusively on physics and mathematics, before specialism in the student’s chosen discipline: *“students didn’t see any engineering until the end of the second year or beginning of the third year. So when the engineering professors received them in the third year, they were really just mathematics students”*. The engineering courses that followed were described to be *“very academic and theory-heavy, with no active learning at all, just lectures with no context”*. Building on this engineering-science knowledge-base, at the close of the degree programme, engineering students were asked to produce an

academic thesis, which typically drew on theoretical principles rather than the practical application of knowledge. As one Academic Dean noted:

“the education system was focused on the technical. Everything was centred on the discipline – how to learn mechanics or processing – but they did not look at the skills... Students were strongly prepared in terms of the discipline, but it was up to them to learn how to apply this knowledge once they were working [following graduation]”.

One of the most striking features of the traditional Chilean engineering degree programme was its length. Up until very recently, all professional undergraduate engineering degrees in Chile (which are collectively referred to as ‘Civil Engineering’ degrees) were at least six years in duration. With low progression rates a feature at many universities, it was not uncommon for the completion time for a bachelor programme to extend from six years to eight or nine years. Most Chilean engineering curricula were also characterised by little to no interaction with industry or the broader community.

3.2. SHIFTING ATTITUDES TOWARDS RETENTION AND EARLY COURSE-LEVEL REFORM

The traditional model of engineering education in Chile described in

Section 3.1 remained largely unchallenged until the early 2000s. In the decade up to 2000, student participation in Chilean universities had grown by 142%, with a marked increase in the numbers of ‘first generation students’: *“students that were the first in the families ever to go to university”*. With this larger, more diverse student body came a wider range of academic achievement amongst the undergraduate intake, which had the effect of further reducing retention and progression rates: in 2009, only 42% of Chilean students successfully completed their degree (OECD, 2009). Amongst Chilean engineering students, drop-out-rates often approached 50% in the first year of study alone. Mirroring experiences from elsewhere in the world (Yoder, 2012, Thayer, 2000, Atman et al., 2010), however, retention and progression rates were disproportionately low amongst first generation students.

A number of interviewees suggested that low retention rates were often *“seen as an indicator of rigour”* by engineering faculty. As one former Dean commented, *“many of the professors saw the first year as a boot camp, to weed out people who did not have what it takes to be an engineer”*. From the early 2000s, however, attitudes to Chile’s low retention rates started to be challenged. One interviewee, who has spent many years as an advisor to the government, suggested that the country’s ambitions to join the OECD played

an important role in triggering this cultural change across the government and higher education sectors:

“the change in mindset came because of the exposition of Chilean faculty to international experience and exposure to quality. When Chile started to participate with the OECD, in the early 2000s, this change accelerated. There was a huge gap between the European concept of quality and the Chilean concept of quality. For other countries, retention was an indicator of quality, but for Chile, it was the opposite”

It would take a number of years before engineering schools, supported by programmes such as *MECESUP*, would establish strategic programmes to address student engagement and retention. However, from the early 2000s, a number of faculty started to establish stand-alone courses that were designed to build student engagement and contextualise engineering learning. Most were framed around project- or problem-based learning. Examples of these new introductory courses included *Engineering Challenges*, introduced at UC in 2002 (see Case Study 5 in Section 4) and *Building My Dreams*, introduced at UoCH in 2001. In most cases, the pedagogical approach and learning outcomes for these new courses were in sharp contrast to the rest of the undergraduate

engineering curriculum. International evidence published at the time and since (Felder et al., 1998, Knight et al., 2007, Atman et al., 2010) suggests that such collaborative and active ‘real world’ engineering experiences early in the degree programme can have a significantly positive impact on retention, progression and student engagement.

Other changes to Chilean engineering curricula were instituted at this time. For example, a number of engineering schools established stand-alone courses to introduce engineering students to the theoretical concepts underpinning professional skills. A small number of engineering schools across the country – such as the University of Santiago (USach) – also started to integrate industry placements into the summer vacation periods as a mandatory element of the undergraduate degree.

In 2002, a voluntary system of accreditation for engineering degree programmes was introduced across Chile⁷. For a number of the early participants, the process of review and evaluation involved in the accreditation process *“helped us to see our weaknesses more clearly”*. The issues of student retention and progression were again revealed as key points of concern. As one Dean commented, *“when we did the accreditation, we had to check our [completion] times. When we saw them, we said ‘wow, we have a problem’”*. Despite an increasing focus

⁷ Accreditation for professional Chilean engineering degrees became compulsory in Chile in 2007.

within Chilean engineering schools on the need to improve student retention, a number of interviewees noted that the wider culture amongst engineering faculty continued to work against their engagement with addressing this issue. One Associate Dean summed up this culture in the following way: *“this is not our problem, it is the problem of the high schools. We are doing a good job and there is no need to make a change”*.

3.3. THE EMERGENCE OF SYSTEMIC EDUCATIONAL CHANGE

The mid-2000s saw the first wave of universities competing for and receiving Phase 2 *MECESUP* funding for systemic educational reform. With these grants came an expectation that recipient universities would engage in benchmarking. In consequence, faculty at these universities became exposed to educational practice and networks of support from outside the country. Faculty and senior university managers travelled across the world, observing alternative educational approaches and building connections.

This wave of international networking and outreach coincided with the growth of the CDIO⁴ initiative, an international network supporting educational reform and the integration of active learning into the engineering curriculum. As a result, Chilean universities were

amongst the first in the world to join CDIO. Drawing on these international connections and educational ideas, a growing number of engineering schools across Chile started to redesign the first-year curriculum, to provide a more coherent introduction to the engineering disciplines, to provide a context for their studies and build cohesion and engagement across the student body.

One engineering school to embark on a programme of reform at this time was the Catholic University of the Most Holy Conception (UCSC). More than 70% of the students at this small private university are from low income backgrounds and the first generation to enter higher education. The reform responded to concerns about an *“overloaded and inflexible curriculum”* as well as poor retention and progression rates. Following the receipt of a Phase 2 *MECESUP* grant in 2006, UCSC embarked on a process of international benchmarking. This process sought, in particular, to consider how the integration of project-based, active learning might help to improve student engagement and retention, as well as improve technical, personal and interpersonal skills. Solange Loyer, who led curricula reform in the Department of Civil Engineering, noted how the experiences of visiting Sherbrooke University⁸ in Canada and Olin College of Engineering⁹ in the US marked an important change in faculty attitudes

towards non-traditional educational approaches:

“at the beginning, professors thought that students could not do anything in their first year. That they did not have enough knowledge to solve these problems. But after seeing these things happening [at the benchmark universities], they said yes, students are able to do these things”.

In 2008, UCSC started to engage with the international CDIO network, which subsequently had a major impact on the design and progress of the educational reform. Using the CDIO standards¹⁰ as a guide, the engineering school *“mapped out all of the learning outcomes for our graduates”* and redesigned a new curriculum from the bottom-up, infused with authentic active learning experiences. One important element of the reform was the establishment of new student-centred courses, in each of the five engineering departments, to introduce incoming first-year students to their engineering discipline.

3.4. THE FOCUS ON DEGREE DURATION AND WIDENING PARTICIPATION

The mid-2000s also brought a growing national debate about the length of Chile’s engineering degree programmes. Concerns were raised both by

8. Sherbrooke University (<http://www.usherbrooke.ca>)

9. Olin College of Engineering (<http://www.olin.edu>)

10. CDIO Standards (<http://www.cdio.org/implementing-cdio/standards/12-cdio-standards>)

the government and sections of the higher education community that the length of the standard degree was both limiting international student mobility and placing an unnecessary strain on students' families, who are the major contributor to university tuition fees in Chile. In 2006, a government-funded project was launched to drive curricula reform and reduce the engineering degree duration from six to five years at UC and UoCH, Chile's two premier universities. Educational reforms at the two universities were implemented from 2007. Changes focused on establishing a new outcomes-based curriculum structure, with fewer contact hours and a greater emphasis on self-study, as well as an integration of new team-based projects using a design-build approach.

Reducing the length of the engineering degree, however, proved to be a significant challenge. Indeed, the wider national drive to reduce the duration of Chile's engineering degrees has been fraught with difficulty and has met continuing faculty resistance over the past decade. Faculty concerns centred around maintaining academic standards: *"there is so much pride in Chile about the length and rigour of the curriculum...change is timid because people want to ensure that the knowledge is retained"*. The lengthy engineering degree was seen as an important mechanism to rectify deficiencies in the students' high school education, thus ensuring the quality and consistency of the Chilean engineering graduate. Chilean industry also

expressed unease about the potential negative impact of a shorter degree programme on the academic attainment levels of engineering graduates. In consequence, a significant proportion of the initiatives to shorten engineering degrees over the past decade quickly stalled or only realised a fraction of the planned reductions.

Some engineering schools, however, have successfully implemented reductions to the length of their degrees. The schools that have made this change tend to be amongst those that have engaged in systemic reform of the curriculum structure – such as Catholic University of the North (UCN), UC and Adolfo Ibáñez University (UAI) – and that have therefore been able to create a coherent 4-, 5- or 5.5-year programme. A number have also sought to combine a shorter degree programme with opportunities for greater student choice and flexibility. For example, UAI is currently *"working towards a four-year degree"*, where students can opt to spend a final, fifth year either on a masters project (for those intending to follow an academic career path) or on an industry internship (for those intending to work as a professional engineer following graduation). Many interviewees anticipated that engineering schools across the country would start to follow similar models over the coming decade, particularly in the context of the heated national debate about the cost of university education.

The past decade has also seen growing concerns about widening participation

in Chilean higher education. Across the country, students' background is a major determinant of access to higher education and the economic benefit it secures. An advantaged background and attendance at private secondary school are strongly associated with academic success and economic security later in life. According to OECD figures (OECD, 2014), 37% of 15-year-old children in Chile attend a public 'state' school, while 48% attend a subsidised government school and 14% attend a private school. Privately-educated children are more than twice as likely as their state-educated peers to enrol in higher education: in 2010, 76% of privately-educated students in Chile enrolled in higher education compared to 33% of state-educated students (OECD, 2013). In turn, a higher education degree provides graduates with a considerable earnings advantage: Chilean graduates earn 2.6 times more than their secondary-educated counterparts, constituting the greatest earning differential for higher education qualifications in the OECD (OECD, 2015).

One institution that has taken great strides to tackle the issue of student access and widening participation is the University of Bio Bio (UBB), a university whose student population is drawn predominantly from low-income households. As outlined in Case Study 2, through curricula reform, a new first-year support programme and a student internship, the university has significantly reduced dropout rates and improved progression rates across the

whole institution. Although the interventions were applied university-wide, many were first developed or piloted within the engineering discipline.

In addition to initiatives at an institutional level, a growing number of engineering schools have also started to address the imbalance in the socio-economic profile of their student intake. Some established partnerships with local high-schools to offer targeted academic support and mentoring. For example, UCN – a university where a high proportion of students are drawn from middle-to-low income families – has established a high-school liaison programme *“to generate an accelerated extracurricula process that facilitates the entering and continuity of the students to the university”*. Others have established a dedicated entry route for admission to the engineering degree for state-educated students and/or those from poorer backgrounds. For example, in 2010, the engineering school at UC established the *Talent and Inclusion* initiative. Prior to this time, as a CRUCH university, entry to the engineering school at UC had been determined by the standardised test scores achieved by students at the close of their high-school education. The UC engineering school established an additional route for entry – which now accounts for over 10% of the annual intake of 750 students to the school – targeting the top 10% of state school students and selecting candidates using a combination of IQ tests, interviews and standardised test scores.

From 2016, the school has started to provide dedicated support and mentorship to the incoming cohort of around 100 students admitted annually through the Talent and Inclusion programme. UC has also developed a Women in Engineering programme to *“strengthen the community of future, current and former female students”*. Activities include a boot camp for female students (to *“give [them] essential tools of leadership and self-awareness to face the entry to a workplace”*), training engineering students as 'Ambassadors' (to inspire and engage high school children) and organising an annual gathering of 'Outstanding UC Women Engineers' (to showcase and celebrate the successes of women engineers).

CASE STUDY 2: UNIVERSITY OF BIO BIO

The University of Bio Bio (UBB) is a public university located in Concepcion, Chile's second-largest city. More than two thirds of the university's undergraduate enrolment are first generation students and 80% come from low-income families (defined as those within the lowest 60% household-income bracket nationally).

In 2008, UBB launched a major programme of educational reform, supported by a US\$4.6m grant from *MECESUP*. The initiative focused on three areas of concern: student retention, time to degree completion and graduate employability. Mirroring the national picture, retention rates at the university were low: in 2008, 17% of students had dropped out by the end of their first year, 40% had left by the end of their third year and less than half completed their studies. Progression rates were also low: the average completion time for the six-year degree programme was 8.5 years. Concerns had also been raised by industry partners about graduates' lack of work-based personal and professional skills, reflecting the traditional disciplinary-focus of the curriculum at the time. The university recognised that these issues were particularly acute for low-income and first generation students, with this group facing particular challenges in their journey into and through higher education. As Aldo Ballerini, Academic Dean for the university, explained:

"it is tough for students coming from families who haven't had any information about university, who are the first generation in university. The cultural capital is not high. The transition from

high school to university was huge for them... The main seal of our university is social responsibility, so we wanted to find out how to help these students".

As outlined in Table 1, the reform comprised three components. With each subsequent component, the focus on the university's poorest students sharpened, with the **curricula reform** impacting all students, the **First Year Induction and Integration Program** targeting the 80% of students from low-income families and the **Cultural and Professional Internships** available to a restricted number of students from the poorest backgrounds. Activities such as the internships required sensitive design and delivery on behalf of the university, to ensure that they were not stigmatising for the students involved.

The interventions have been associated with a marked improvement in student engagement and progression: by 2014, dropout rates in the first year of study reduced from 17% to 10.5% and average time to degree completion reduced from 8.5 years to 5.9 years.

Building on this foundation, in 2014, UBB launched the Bridge Program, connecting the university with local state high schools. Thirty professionals, employed by the university, work with high school teachers, parents and the local community to improve classroom practice and *"to help to prepare students to get into the higher educational system"*. The first cohort of students participating in the Bridge Program will enter higher education in 2017.

Table 1. Components of the educational reform at UBB

Focus of activity	Details
Curricula reforms	<p>The curricula reforms focused in three broad areas:</p> <ul style="list-style-type: none"> • Personal and professional skills: a new outcomes-based curriculum was established requiring every university course to support the development of personal and professional skills (such as teamwork, entrepreneurship, leadership and social responsibility) in addition to disciplinary-specific learning outcomes; • Credit transfer system: the university established a formal system to evaluate and credit the skills developed and demonstrated by students – such as teamwork, leadership and communication – during extracurricula activities; • Basic science modular curriculum: basic science courses, taught during the first two years of study, were redesigned and divided into six-week modules, rather than extended across 18-week semesters. Students were able to resit failed modules while still continuing their studies, rather than having to repeat semesters, allowing pass rates to increase from 60% to 90%. Aldo Ballerini noted that these early experiences of success can have a lasting impact on students' engagement and self-belief that can extend throughout and beyond their studies, <i>"this change helped students prepare emotionally for student life – they realise that they are able to pass"</i>.
First Year Induction and Integration Program	<p>The <i>First Year Induction and Integration Program</i> is designed to provide structured support and advice for students from low-income families during their first year of study. More than 1700 students across the university are now enrolled in this programme. Specifically-trained graduate tutors are each assigned 12 incoming students, providing them with four hours of support each week to address disciplinary, social and practical concerns. Throughout the year, students' attainment and integration into university life is monitored by both graduate tutors and the programme disciplinary leaders. Overlaying this ongoing support, the university also provides four formal 'touch points' for this student cohort during the year:</p> <ul style="list-style-type: none"> • Welcome for new students: during the first few days of the academic year, university senior management visit each department to introduce incoming students to the university and their programme of study; • Identification of early issues: in the middle of Semester 1, the full cohort of students on the programme meet to discuss some of the challenges that they are facing and develop shared strategies to overcoming them; • Self-assessment: at the beginning of Semester 2, students self-evaluate their academic progress and wellbeing, outcomes of which are discussed with graduate tutors, professors and directors of studies; • Flagging 'at risk' students: in the middle of Semester 2, students at risk of failing the first year of study are identified and offered one-to-one support from graduate tutors, professors and programme leaders.
Cultural and professional internships	<p>Designed <i>"to widen students' cultural horizons"</i>, <i>Cultural and Professional Internships</i> are available on a competitive basis to students from the poorest 40% of households. With many of these students having never travelled out of the Bio-Bio region, it provides opportunities to visit museums and restaurants in the country's capital as well as travel to companies to meet with potential employers.</p>

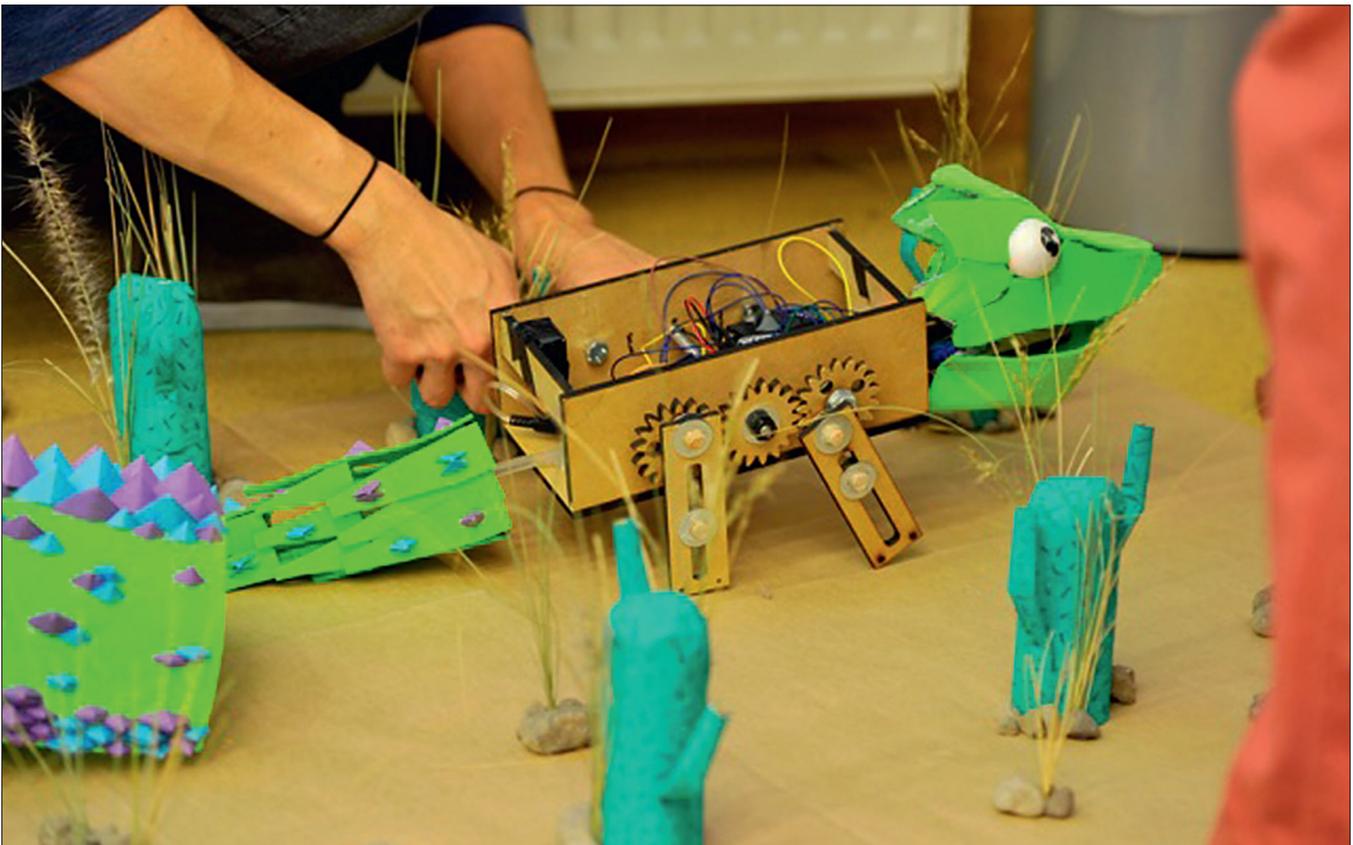
3.5. THE FOCUS ON TECHNOLOGY-DRIVEN ENTREPRENEURSHIP AND INNOVATION

The turn of 2010 brought an acceleration in the pace of change in Chilean engineering education. In 2011, UC launched what is arguably the most ambitious engineering curricula reform established to date in Chile. Key aims included extending the adoption of active learning in the curriculum, offering greater flexibility and choice to students, establishing a greater focus on inter-disciplinarity and forging stronger partnerships with Chilean industry and society. Another central theme in the UC engineering reform was to “develop the ability of discovery, innovation and entrepreneurship in our undergraduate students”. This focus reflects a growing emphasis in engineering schools worldwide on technology-driven entrepre-

neurship and innovation (E&I) within and beyond the curriculum (Byers et al., 2013, Sidhu et al., 2010, Wheadon & Duval-Couetil, 2013). Adoption of E&I has been particularly rapid in the US: in 2011, entrepreneurship was described as “one of the fastest growing academic areas within the nation’s 335 engineering schools” (Besterfield-Sacre et al., 2011).

The integration of E&I into Chilean engineering curricula was accelerated by the launch of *Engineering 2030*, a major programme of strategic government investment established in 2013. As discussed in Case Study 3, *Engineering 2030* sought to embed E&I at the heart of research and education activities within Chile’s engineering schools.

Examples of E&I courses and experiences that have been established in Chilean engineering schools are provided in Section 4.



CASE STUDY 3: ENGINEERING 2030

Historically, the Chilean economy has been strongly dependent on commodities, principally copper mining, fishing, forestry and agriculture. In recent years, the country has sought to diversify and strengthen its economy by driving the national knowledge and innovation base through strategic public-private investments. There is evidence that high profile programmes such as Start-Up Chile have had some success: according to the Global Entrepreneurship Monitor, between 2006 and 2014, the proportion of the Chilean working age population intending to start a business in the next three years rose from 22% to 50% and the proportion that had recently established new businesses rose from 9% to 27%. However, Research and Development (R&D) investment in Chile remains low; at less than 0.4% of GDP, it represents the lowest R&D investment of all OECD countries. The national R&D picture is particularly constrained by low levels of private investment. The Chilean skill-base in R&D is also limited: 0.1% of the Chilean workforce are researchers, representing the second-lowest proportion amongst OECD nations (Mexico has the lowest).

In 2013, as the country set its sights on stimulating economic growth through technology innovation, the Chilean government's National Agency for Innovation and Development (CORFO) launched *Engineering 2030*. The initiative specifically targets Chilean engineering schools as a key incubator for both the talent and ideas to drive this technology-fuelled economy. Its goals are to improve *"the contribution [of engineering schools] to the society through technology-based innovation and entrepreneurship, applied R&D, industry linkages and international alliances, lifting them into a World Class category"*. The launch of *Engineering 2030* was to mark the start of a renewed focus on education reform across Chile's engineering schools, with a strong focus on nurturing entrepreneurial and innovative talent amongst undergraduate and post-graduate populations. Its remit extends beyond educational programmes, however, and calls for wide-reaching reform in areas such as engineering school governance, international alliances, international mobility of staff and students, technology commercialisation and industry-led R&D.

As described below, *Engineering 2030* is structured in two stages.

- **Stage 1 (2013–2014):** Following a call for proposals from engineering schools across the country, 15 projects (involving 20 institutions from across Chile) were selected to participate in Stage 1 of the initiative. With a budget each of US\$100k, participating engineering schools were asked to prepare a proposal for reform built upon two sources of evidence. The first was an international benchmarking exercise, *"to understand how engineering is being taught in other countries, and how these schools relate to society, to industry"*. Taking the benchmarking data as a frame of reference, the second evidence source was an internal diagnostic, *"to identify the weaknesses when compared to the top-ranked engineering schools"* and thereby prepare a proposal for school-wide reform. Stage 1 offered financial incentives for engineering schools to submit proposals as part of a consortium.
- **Stage 2 (2015–2020):** five projects were selected for support during Stage 2 of the initiative, built from various consortia across 10 engineering schools: UoCH, UAI, UC, Federico Santa Maria Technical University (UTFSM), University of Concepción (UDECE), USach, Pontifical Catholic University of Valparaiso (PUCV), UBB, University of La Frontera (UFRO) and Catholic University of the Maule (U Maule). Stage 2 of *Engineering 2030* draws on a US\$60m contribution from CORFO and a US\$55m contribution from the participating universities. Project progress is regularly reviewed by an international panel, and performance is tracked using 70 indicators, ranging from R&D investments from industry to student retention in undergraduate degree programmes.

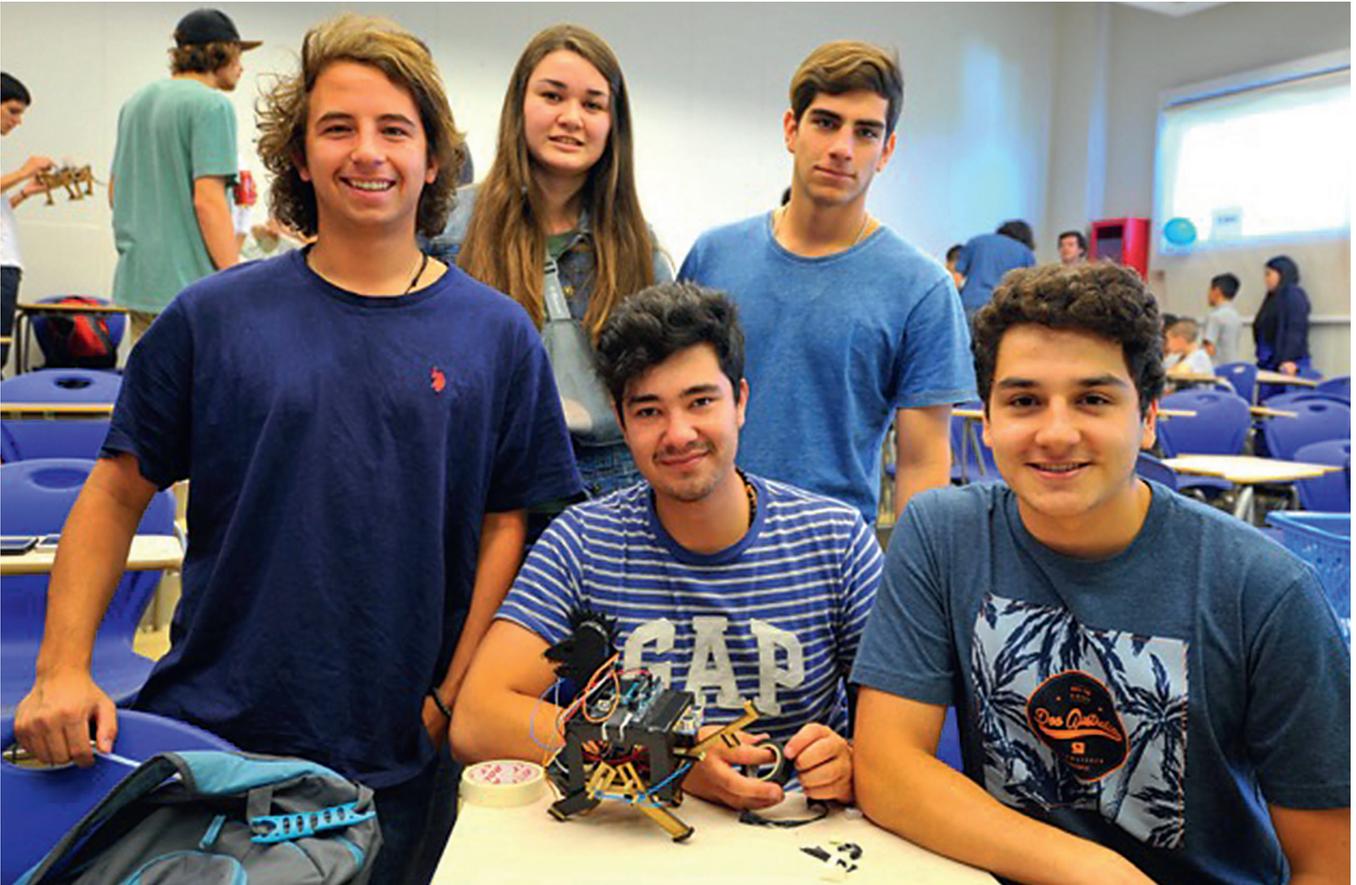
It is interesting to note that the initiative was launched by the ministry of finance, rather than the ministry of education, underlining the strategic importance which the government accords to *Engineering 2030* as a driver for the national economy. As one Dean noted, *"in Chile, we are a developing country that just has raw materials. Universities need to be innovative and collaborate with the development of our country. We knew this, but 2030 put innovation in the first place and focused us on what needed to be done"*.

During the five years preceding *Engineering 2030*, much of the reform activity in Chilean engineering education had focused on the first year of study – in particular, building engagement, contextualising the curriculum and introducing students to the various engineering disciplines. *Engineering 2030* encouraged engineering schools to expand the scope of educational reform to encompass the curriculum as a whole. In particular, universities involved in the second phase of *Engineering 2030* have focused on creating a more flexible curriculum, underpinned by problem-solving, creativity and innovation. Internationalisation has also been a growing theme in many Chilean engineering programmes. For example, UAI are offering a range of opportunities for engineering students to study and work abroad in their fifth year of study and USach are delivering an increasing number of their engineering courses in English.

The years since the launch of *Engineering 2030* have arguably seen the most intensive focus on engineering educational change across Chile. A growing number of engineering schools have implemented (or are in the process of implementing) root-and-branch reform of their undergraduate

curriculum: examples include UC, UAI, UCSC and UCN. The renewed drive for educational reform has also highlighted the need for greater faculty support and professional development in teaching and learning. In response, a number of engineering schools have established engineering-specific teaching and learning centres, with faculty training and professional development a major focus of activity. Examples include the ADD¹¹ at UoCH and the *Center for Engineering Education* at UCN. In addition to these formal support units for engineering teaching and learning, informal communities of support have started to emerge, aimed at sharing experiences and offering peer-support across the different engineering disciplines. For example, in 2012, the *Faculty Learning Community* was established in the engineering school at UCSC to support the ongoing educational reform through the wider adoption of active learning. In a second example, one of the Engineering 2030 consortia – comprising USach, UDEC and PUCV – has recently established joint training and workshop activities offered across all three institutions “to improve the teaching and learning capacity of professors and help them to teach through active learning”.

11. ADD, University of Chile (<http://escuela.ing.uchile.cl/add>)



Examples of good practice in engineering education



This section highlights examples of good practice in engineering education from across Chile. It will draw out some of the prominent themes running through these exemplars, including:

- project-based and problem-based learning;
- industry collaboration;
- service learning;
- entrepreneurship and innovation (E&I);
- engineering design;
- co-working spaces, particularly those focused on E&I.

As many of the exemplars cut across more than one of the themes listed above, programmes have been categorised under the theme that featured most prominently in the descriptors used by the activity leaders during the interview phase of the study. As will be noted in the text, these areas of innovative practice in Chile are supported by and contribute to wider international trends in engineering education.

4.1. PROJECT-BASED AND PROBLEM-BASED LEARNING

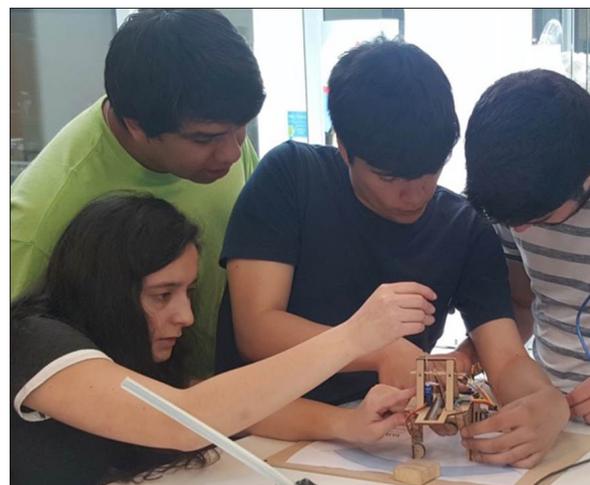
Reflecting trends in engineering education worldwide (de Graaff & Kolmos, 2006, Yadav et al., 2011, Litzinger et al., 2011), project-based and problem-based learning have been prominent features of curricula reform in Chilean engineering schools over the past decade. As noted in Chapter 2, early reforms in Chilean engineering education often focused on the first year of

study as a means to increase student engagement, contextualise engineering learning and introduce students to the engineering disciplines. Many of these initiatives are multidisciplinary and are delivered at relatively large scales. For example, as part of a major curriculum reform initiated in 2007, UoCH established *Introduction to Engineering* as a mandatory first semester course for all incoming engineering students. The cohort of around 1000 students, divided into 16 groups, are tasked to develop prototype solutions to real engineering challenges. In a second example, again called *Introduction to Engineering*, all 2000 incoming engineering students at USach participate in a common course during their first semester. Working in mixed teams taken from across the nine disciplines in the engineering school, students are challenged with a different 'investigation' each week, and are asked to present their findings to the rest of the class. A number of the departments at USach also offer complementary, disciplinary-specific experiences for first-year students during their second semester of study. For example, *Introduction to Electrical Engineering* tasks around 200 students to work on team-based challenges which are assessed through reports and oral presentations. The challenge varies each year: in 2013, teams were asked to design, build and control a mobile robot through a pre-defined pathway; in 2014, teams were asked to develop a working plan of the electrical installation in their homes.

A number of universities have taken the incorporation of project-based

learning further, integrating it as a spine around which the curriculum is structured. For example, the new engineering curriculum at UCN draws extensively on project-based learning (see Case Study 6 in Section 5). A second example is from UAI as illustrated in Case Study 4, where the curriculum is structured around project-based *Workshops*.

Linked to project- and problem-based learning, another growing area of focus in engineering schools across Chile is the development of extracurricula experiences. These developments mark a significant departure from practice ten or even five years ago, when few non-curricula activities for engineering



University of Chile (UoCH)
Introduction to Engineering



University of Chile (UoCH)
Introduction to Engineering

CASE STUDY 4: ADOLFO IBÁÑEZ UNIVERSITY

Adolfo Ibáñez University (UAI), a small private university with campuses on the outskirts of Santiago and the hills of Vina del Mar, first started offering engineering degree programmes in 1989. Building upon systemic curricula reform in 2007, the engineering school rolled out a substantial programme of educational change in March 2016.

The new engineering degree drew its inspiration from programmes at premier universities from across the world, including UCL and Imperial College in the UK and Columbia University and Harvard University in the US, and was supported by a partnership agreement with Olin College of Engineering. The four-year curriculum is structured around four core components:

- **Liberal arts:** one course per semester of the engineering curriculum is devoted to 'broadening' subjects such as communications, politics, ethics, history and leadership;
- **Basic science:** 25% of the curriculum is devoted to basic science subjects, including mathematics, physics and chemistry;
- **Engineering sciences:** almost 50% of the curriculum comprises courses in the engineering sciences. The school is seeking to develop an active-learning approach within many of these courses. For example, in 2016, the introductory Computer Science course was inspired by the CS 50 course offered by Harvard University, which aims that the students think algorithmically and is delivered using a flipped-classroom approach, where students are asked to engage with key topics both before and during the class via an online peer-learning community;
- **Workshops:** almost 25% of the curriculum is devoted to problem-based challenges, by means of one-year-long course in each of the four years of the undergraduate degree, as described in more detail below. Preparatory classes – focused on topics such as design, creativity, electronics and prototyping – have been introduced in advance of *workshops* to ensure that "*students have the basic information they need to solve the problems*".

Alejandro Jadresic, Dean of the Faculty of Engineering and Science at UAI, noted the pivotal role played by the *workshops* within the UAI engineering curriculum: "*we want the students to be engineers from the start. The workshops are designed to integrate the knowledge learnt in the other courses, to get them solving problems... [and to build] their at-*

titudes, teaching them to work in teams and communication skills... so that our students can solve real problems, integrate technical knowledge with entrepreneurship and innovation and change how society works”.

In each year, *Workshops* focus on a specific theme, which broaden in focus and build in complexity as students progress through the undergraduate programme:

Year 1. **The Art of Engineering:** the first year *Workshops* are themed around nature and are focused on building engagement and allowing students to relate basic mathematic and scientific principles to the world around them. Taken by 650 students from across all seven engineering disciplines in both campuses, the *Workshop* challenge changes each year; for example, one theme was to model the mechanics of the jumping cricket.

Year 2. **Design Engineering:** the second year *Workshops* are themed around the person, where students are asked to design and develop solutions based on their observation and analysis of user need. For example, the Applied Sciences *Workshop* asks students to work with schoolchildren from local primary schools to design electronic toys. As Alejandro Jadresic explained, interaction with and feedback from the schoolchildren plays a significant role in the *Workshop's* learning outcomes and assessment: *“the school kids have to grade our students, so students don't just have to think about their design, but also how the schoolchildren are motivated”.*

Year 3. **Entrepreneurship and Innovation Technology:** third year *Workshops* focus on developing technology-driven solutions to address societal problems and design entrepreneurial ventures.

Year 4. **Capstone project:** in the final year, the capstone project focuses on developing solutions to authentic global issues, largely posed by industry. At the close of the *Workshop*, student teams present their final solution to a judging panel of professors and ‘company officials’.

During the recent curricula reforms, the *Workshops* were redesigned to re-shape their approach, improve their connectivity with the rest of the curriculum and ensure that they support and consolidate students’ growing professional and technical competencies across the four years of study. The first cohort of bachelor students at UAI will graduate from the new degree programme in 2020.



students existed, particularly outside Santiago. Many of the new extracurricula activities offer students hands-on or problem-based experiences, often in team-based environments, with many also focusing on societal and/or entrepreneurial challenges. For example, a university consortium founded through *Engineering 2030* comprising USach, UDEC and PUCV, recently established Innovation and Integration (I2), an annual inter-institutional extracurricula competition for engineering students. Two hundred engineering students from the three universities camped onsite at a stadium in USach to tackle team-based challenges over the course of three days, such as creating a device to catch a falling egg from the greatest height. A series of challenges was also posed by the Chilean ministry of transport and the local city government, where student teams were asked to create design ideas “to improve traffic and transport in Santiago” including “to reduce accidents in a traffic black-spot in the city”. Student engagement levels at this extracurricula event were noted to be high; at USach alone, 240 engineering students competed for the 60 places available for participation.

4.2. INDUSTRY COLLABORATIONS

A feature of some of the strongest engineering programmes across the world is the opportunity for students

to tackle ‘real world’ problems posed and support by industry partners. Examples include *Engineering Design Challenges*¹², for all 1000 first-year engineering students at the University of Queensland in Australia, and the *Learning Factory*¹³, a capstone design experience for final-year engineering students at Penn State University in the US.

Although, as noted in Section 6.4, partnerships between Chilean engineering schools and industry are limited, a small but growing number of experiences have been developed to expose students to authentic industry problems. Many of these experiences are integrated within the capstone project in the final year of study. For example, UCN has offered a capstone project since 2013, where students are tasked to solve real industry problems as “the culmination experience of the new curriculum” in the engineering school. This team-based project lasts either one semester or one year, and has already drawn on collaborations with 25 national companies. In a second example, each year UTFSM invites 10-20 industry representatives to meet with final year students and discuss key issues and challenges facing their businesses. Students are then allocated to 10 groups, each of which tackles one of these challenges over the course of the year.

12. *Engineering Design Challenge, University of Queensland* (<https://www.eait.uq.edu.au/student-engagement-through-engineering-design-challenges>)

13. *Learning Factory, Penn State University* (<http://www.lf.psu.edu>)

4.3. SERVICE LEARNING

Another growing theme in Chilean engineering education is service learning, with engineering students in an increasing number of universities being asked to use technology to address national and global challenges facing society. Service learning has grown significantly in engineering programmes across the world in the past two decades (Litchfield et al., 2016, Lehmann, 2008). High profile examples include EPICS¹⁴ (Engineering Projects in Community Service), established at Purdue Univer-

sity in 1996, and the EWB Challenge,¹⁵ a cross-cultural development project for first-year engineering students rolled out in universities across the world.

Chilean examples of engineering service learning include the *Service Learning Project* embedded into the first-year *Introduction to Civil Engineering* course at UCSC. Established in 2015, the course is delivered in collaboration with a different regional community partner each year. At the start of the course, students are assigned into small teams and asked to work with

the community partner to explore their needs and priorities, and develop ideas, grounded in civil engineering, that could improve their everyday lives. The three ideas with the highest potential are selected by the course teaching team, and presented to the community partner, that subsequently “picks the winning project”. In 2015, the community partner was a regional foster home for children, with the ideas proposed by student teams ranging from the creation of bicycle paths to the building of a “wood jungle gym”. The winning project eventually selected by



Catholic University of the Most Holy Conception (UCSC)
Service Learning Project at the Bernadette Serrano Foster Home, 2015



¹⁴ EPICS, Purdue University (<https://engineering.purdue.edu/EPICS>)

¹⁵ EWB Challenge (<http://www.ewbchallenge.org>)

the foster home was a small basketball court. During the second half of the course, the full student cohort work collaboratively on the chosen project. Students are divided into new groups, each focused on a key project task, such as design, marketing, fundraising and construction. Reflecting “a real engineering environment”, team leaders from each group must coordinate together to ensure that the project is successfully managed and delivered to the community partner. At the close of the project, the full year cohort works together on site to construct the design and present it to the community partner. In the 2016 delivery of the course, the community

partner – a small neighbourhood close to the university – selected a project to create “a carved wooden sign telling the story of the neighbourhood”. Following completion of the planning and preparation for this project, students groups built the sign at the heart of the community. The *Service Learning Project* at UCSC is supported by a small service learning centre in the engineering school. The centre helps to coordinate a number of new service learning experiences across the engineering school through establishing agreement protocols with community partners and providing assessment tools that reflect the student learning outcomes for such experiences.

Social responsibility has also become an increasingly prominent theme within and beyond the engineering curriculum at UC. For example, the school offers one- or two-month internships in social institutions such as NGOs and B Corps; in 2016, 400 applications were received for the 100 internships available. Since 2013, the school has also offered opportunities for students to work with an orphanage in Tanzania, where they are able to work together with the children and the local community to tackle some of the everyday challenges faced. The school also offers a suite of programmes in social innovation and entrepreneurship, such as an annual Social Entrepreneurship Week (offering students activities, seminars and visits, supported by regional social entrepreneurs) and an annual Social Ideas Camp (to support and advance



Catholic University of the Most Holy Conception (UCSC)
Service Learning Project at the Lo Mendez neighbourhood, 2016



Pontifical Catholic University of Chile (UC)
UC Engineers Defying Borders in Tanzania

social entrepreneurship ideas from engineering students across Chile).

Other examples of service learning experiences in Chilean engineering education include the *Factoria* from the University of Desarrollo (UDD) (as described in more detail in Section 7) and *Building My Dreams*, a first-year course at UoCH where "student teams are paired with small businesses in poor regions of Chile". Interview feedback suggested that service learning is likely to play an increasingly prominent role in Chilean engineering curricula in the coming years, with many engineering schools currently planning the development of new service learning courses.

4.4. ENTREPRENEURSHIP AND INNOVATION

Supporting the establishment of *Engineering 2030*, E&I is becoming an increasingly prominent feature in engineering curricula across Chile. In 2015, as part of a broader reform of the engineering curriculum, the engineering school at UC established

Research, Innovation and Entrepreneurship, a mandatory course for all 700 third-year engineering students at the university. Delivered in partnership with the *Sutardja Center for Entrepreneurship & Technology* at UC Berkeley, this semester-long course brings a particular focus on the development of hands-on skills in technology-driven entrepreneurship. Working in teams of five, students are challenged to develop solutions to some of the key issues facing the country, including mining, health and energy sustainability. Teams are offered 'on demand' mentorship both from a UC faculty member, on the process of formulating and developing an idea, and from an industry representative, on the technical aspects of the solution under development. Teams 'pitch' their proposals at a public event at the close of the semester, with the winning project awarded funding to further develop their idea. In 2015, the winning proposal was a non-invasive medical device designed to locate a patient's veins.

In recent years, a number of Chilean engineering schools have also developed

E&I experiences for students outside the curriculum. Significant activity has been focused on the establishment of competitions to support students' technology-driven entrepreneurial ideas, such as *UAI Prototypes* at UAI and *Lions Up*¹⁶ at USach. UC, in particular, has driven forward a range of extracurricula activities focused on E&I. Examples include *The Bridge*,¹⁷ an opportunity for students to spend two months in Silicon Valley, and *BRAIN*¹⁸ (Business-Research-Acceleration-Innovation), "a competition of scientific-technological businesses for projects that already have an alpha prototype or proof of concept" that has recently expanded its reach across the country. The UC engineering school is aiming to further expand its extracurricula provision, in order to broaden students' capabilities and opportunities in E&I. It is currently in the process of devising what is termed an *invisible curriculum*, mapping a sequence of extracurricula activities to support the development of students' entrepreneurial capabilities for each of three entrepreneurial pursuits:

- science and technology-based

ventures;

- apps and IT;
- social innovation ventures.

This *invisible curriculum* is expected to be rolled out at UC in 2017.

4.5. ENGINEERING DESIGN (IN AN E&I CONTEXT)

A number of the new courses and student experiences in engineering E&I are also underpinned by engineering design, often in an interdisciplinary setting, which is emerging as a growing area of expertise in Chilean engineering education. Notable international exemplars of E&I taught within an engineering design context can be seen at Olin College of Engineering¹⁹ and Imperial College London.²⁰ Examples from Chile include the *dLab*,²¹ established at UDD in 2012 "to teach innovation to final year students". This elective – comprising 60% of the fifth year of study – is open to engineering, design and business students at the university. Working in multidisciplinary teams, the two-semester course asks students to develop solutions to two challenges, drawing on the university's

¹⁶ *Lions Up*, USach (www.lionsup.cl)

¹⁷ *The Bridge* (http://www.ingenieria2030.org/outcome/the_bridge/)

¹⁸ *BRAIN* (<http://www.brainchile.cl>)

¹⁹ *Affordable Design and Entrepreneurship*, Olin College of Engineering (<http://design.olin.edu/courses/ade/>)

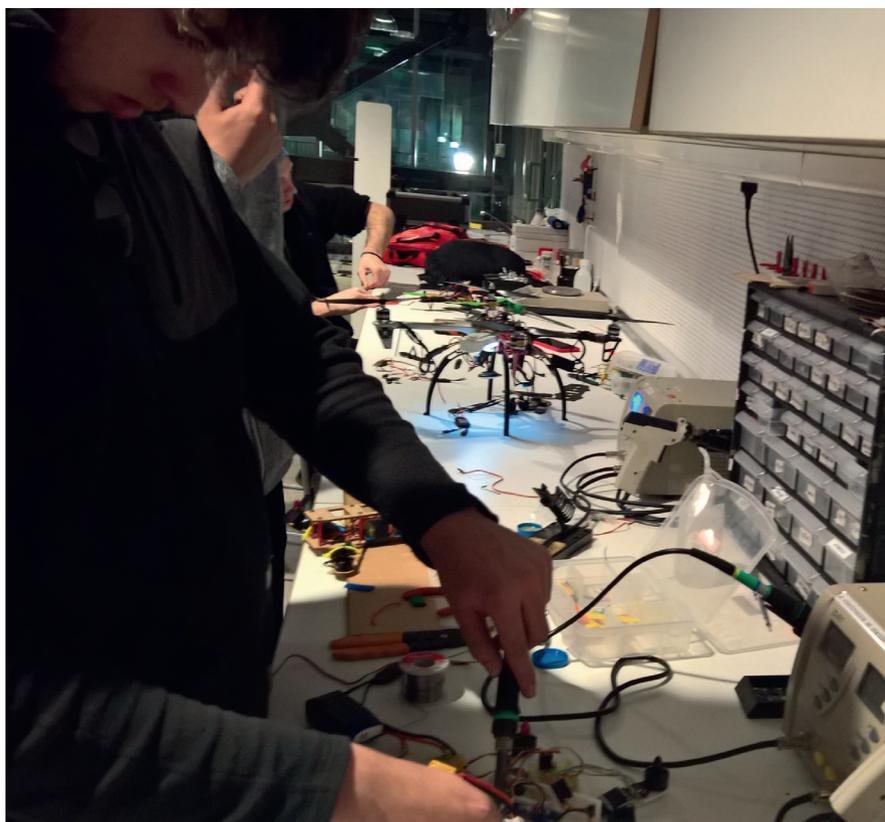
²⁰ *Design Engineering*, Imperial College London (<http://www.imperial.ac.uk/design-engineering/study/meng/>)

²¹ *dLab*, UDD (<http://icubo.udd.cl/programas/dlab/>)

prototyping workshop to develop their ideas. In the first semester, all teams tackle a common challenge: in 2016, this was focused on 'frugal health innovation', where the ideas and prototypes developed were based on the students' interactions with a local hospital. During the second semester, teams work with an assigned company, ranging in size from regional startups to the second largest airline company in the country, to solve specific problems facing their business. In a second example, the engineering school at UAI recently established the *Design Lab*,²² with a new masters in engineering design²³ which brings together students from across different disciplines and offers a strong focus on E&I, creativity and problem-solving.

The engineering school at UC has also developed a number of programmes and experiences that bring together E&I with user-oriented design. For example, *Engineering Challenges*, as described in Case Study 5, is an introductory engineering course where incoming students are asked to design and prototype solutions to major societal challenges. UC also offers a Major in *Engineering Design*,²⁴ operating out

of the school's design lab (*DiLab*)²⁵ and open to 50 final-year engineering undergraduates. Following studio-based courses in topics such as *Visual Thinking and Design Anthropology*, the Major culminates in a capstone project where "a company comes with a problem to be solved by the students". Each company contributes US\$2k towards prototyping materials and team costs, and also provides mentorship and support to teams as they develop solutions.



22 *Design Lab*, UAI (<http://www.uai.cl/facultades/designlab>)

23 *Master in Design*, UAI (<http://www.uai.cl/postgrados-y-diplomas/master/listados>)

24 *Major in Engineering Design*, UC (www.di-lab.cl/major)

25 *DiLab*, UC (www.di-lab.cl/)

CASE STUDY 5: ENGINEERING CHALLENGES, UC

Engineering Challenges is a mandatory first-year course established at UC in 2002. Working in teams of seven, all 750 incoming engineering students at the university are tasked to “develop a physical prototype for solving a real societal problem... that has to be completely new, completely creative”. The course is designed to introduce new students to the range of engineering disciplines, provide hands-on experience of the engineering design process and build student engagement in a creative team-based environment. The challenge posed changes each year. In 2016, the theme was ‘Clean Chile’, with projects focused on “conceiving, designing and building an innovative prototype of a device that contributes to the reduction of garbage in the city”. Juan Carlos de la Llera, Dean of the Faculty of Engineering at UC, noted that the authenticity of the challenges, and their relevance to Chilean society, have proven critical to establishing high levels of student engagement:

“one year we asked them to build emergency housing for low-income families only with recycled materials that could be appropriate for the weather and conditions of Chile. This connected students with a real, authentic problem. They went to the slums of the city and talked to the people. It gave them a sense of responsibility because, at the end, there was a real family that was going to take this home”.

The semester-long course takes a highly structured approach, introducing students to each successive stage of the user-based design process in turn, allowing teams to apply the principles step-by-step within their evolving projects. For example:

- early weeks of the course are concerned with an assessment of the challenge context – through data gathering/analysis and interviews with a wide pool of users and subject experts – from which teams can then move to evaluate their

design opportunities, hone their ideas and develop a prototype of their chosen solution;

- in the middle of the semester, students from older year groups join the course as instructors for week-long training workshops to develop hands-on design and prototyping skills and “open the students’ minds of what they can do”. Each team member must select a different skill on which to focus during this week – for example 3D printing, CAD design or Arduino – to become the team ‘expert’ in the area;
- through an iterative process, later weeks of the course are concerned with prototype testing, materials selection, mathematical modelling (where needed) and “presenting their process to the professor, TAs and rest of the class for feedback”.

Throughout the semester, three scheduled classes each week focus on the development of skills to support each stage of the engineering design process – such as data analysis, modelling and prototyping – through lectures, group activities and team feedback sessions. A thorough programme of assessment is integrated into the course, both at the individual level (such as through written evaluations of team decision-making) and at the team level (such as through a staggered series of presentations on the team’s research findings and ideas development).

The course culminates with a technology fair, where the teams’ prototype, ideas and research base are presented to a judging panel of users and experts in fields related to the challenge brief. Juan Carlos de la Llera noted the important role played by this expo in injecting a “competitive element” into the course: “students are asked to be creative, produce something completely novel...so there is a lot of privacy from the students – they don’t want others to see their ideas – and there is a lot of pride. This brings the motivations, the interest of the students”.

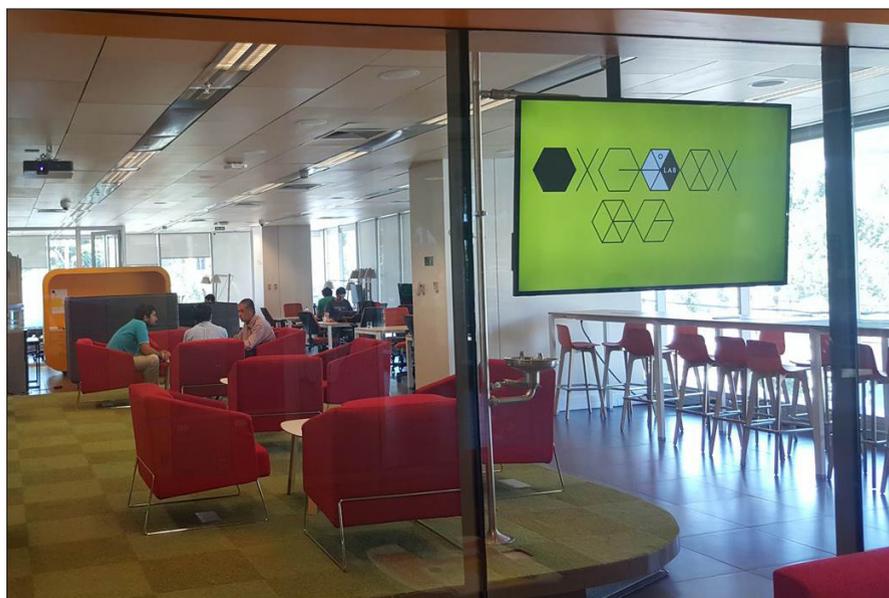
4.6. CO-WORKING SPACES FOCUSED ON E&I

Often drawing on support from *Engineering 2030* (as described in Section 3.5), a growing number of Chilean engineering schools have established co-working spaces focused on E&I that incorporate dedicated prototyping workshops. These hands-on spaces are often student-led, supporting a range of curricula and non-curricula experiences in technology-based E&I. Since the establishment of the first *Fab Lab*²⁶ at MIT in 2001, such spaces have become an increasing feature of engineering schools and universities worldwide. International exemplars include *Skylab*²⁷ at the Technical University of Denmark (DTU) and the *Invention Studio*²⁸ at Georgia Tech.

Chilean examples of E&I-focused co-working space includes *OpenBeauchef*²⁹ in the Faculty of Physical Sciences and Mathematics at the UoCH. Currently benefitting from investment through *Engineering 2030*, this facility is designed to nurture and support the regional entrepreneurial ecosystem. Its ultimate aim is to provide state-of-the-art workshop, co-working and prototyping facilities open to staff, students and the wider entrepreneurial community. Housed within *OpenBeauchef* is *FABLAB*, described as “the largest factory of design and digital manufacture in Chile”. At 500m², the *FABLAB* provides prototyping and desktop space to 50 users. The open-access space is used to support engineering students both during their curricula studies (such as during *Introduction to*

Engineering in the first year of study and *Work Project* in the third year of study) as well those engaged in extracurricular activities and/or entrepreneurial ventures. It is interesting to note that a number of the newly-established E&I-focused co-working spaces in Chilean universities are open-access, and actively encourage participation from communities outside the university. In addition to building the skills and attitudes of their own staff and students, these spaces also seek to establish an entrepreneurial hub that connects the university with society and the regional entrepreneurial ecosystem. For example, *FabLab UC*³⁰ was established at UC in 2014 as a joint initiative between the *Innovation Centre* and the School of Engineering and is described as “a space where professionals, researchers, entrepreneurs and businessmen converge to materialise their ideas and projects”.

Other examples of Chilean co-working space focused on technology-driven E&I include the *iCube*³¹ at UDD, the *DILab*³² at UC and the *Garage UAI* at UAI.³³ The engineering school at USach is also in the process of establishing a *FABLAB*, which will be supported by co-working spaces in each of the engineering departments for students to work on cross-disciplinary projects.



University of Chile (UoCH)
OpenBeauchef

26 *Fab Lab*, MIT (<http://fab.cba.mit.edu>)

27 *Skylab*, DTU (<http://www.skylab.dtu.dk>)

28 *Invention Studio*, Georgia Tech (<http://inventionstudio.gatech.edu>)

29 *OpenBeauchef*, UoCH (http://www.openbeauchef.cl/en_US/)

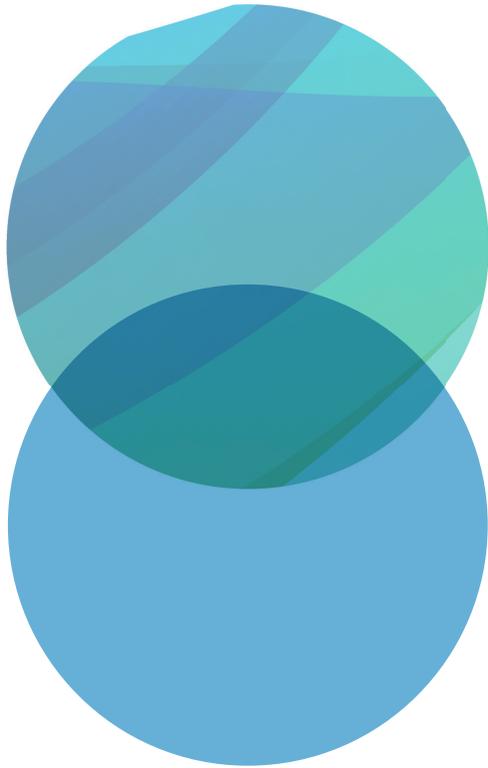
30 *FabLab UC*, UC (<http://www.fablabuc.cl>)

31 *iCube*, UDD (<http://icubo.udd.c>)

32 *DILab*, UC (<http://www.di-lab.cl>)

33 *Garage UAI*, UAI (<http://www.garageuai.cl>)

Factors supporting educational change in Chile



Educational reform in engineering schools worldwide is often piecemeal, driven by a dedicated minority of faculty and slowly built up over time (Heywood, 2006, Fairweather, 2008, Graham, 2012). Chilean engineering education reform stands in contrast to this approach: reforms in Chile have been ambitious, rapid and, in many cases, curriculum-wide. Although challenging to implement successfully, this systemic approach secures important benefits, both educationally and structurally. Systemic curricula reform provides an opportunity to establish a more robust and coherent educational model, with greater connectivity between courses and a more systematic approach to consolidate and build student capabilities in line with the intended learning outcomes. The design and implementation of the reform is also likely to involve engagement from wider cross-sections of faculty and senior management, a feature which is associated with long-term sustainability (Graham, 2012, Kolmos et al., 2015): systemic change is typically not reliant on the tenure of a small number of 'enthusiasts' for its continuation and a broader-base of individuals from across the university hierarchy are more likely to appreciate and champion the benefits of successful curricula reform if its continuation is under threat.

Evidence from the snapshot study suggests that four broad sets of factors appear to have combined to create a national momentum for

ambitious and systemic change in Chilean engineering schools:

- targeted government interventions;
- the leadership of key engineering schools;
- the focus on technology innovation as a driver for national economic growth;
- exposure to ideas, networks and best practices from across the world.

These four factors build on and complement each other and are discussed in turn below.

5.1. TARGETED GOVERNMENT INTERVENTIONS

Two critical government interventions – *MECESUP* and *Engineering 2030* – have undoubtedly had a dramatic impact on the capacity for and implementation of educational change in engineering schools across Chile. Interviews with senior managers and change leaders consistently underlined the pivotal role played by each of these two programmes in initiating and driving far-reaching educational reform within and beyond their institutions:

“MECESUP was a big trigger. It forced the school to go in that direction. If we didn’t have the money behind us, the authority behind us, there is no way we would have made the changes we did”.

“the involvement of the authorities and the support of CORFO has pushed us to go fast. Without the support of government agencies, we might do the same, but it may be in 20 or 30 years”.

External observers and international partners reinforced these points, characterising the interventions as both regionally distinctive and highly successful. One of the study interviewees, who has acted as a consultant to the World Bank for many years, described the *MECESUP* programme as *“the most successful World Bank-financed project in higher education”*. In reference to *Engineering 2030*, another international observer noted:

“In Latin America, Engineering 2030 is unique. You don’t see any other country in Latin America where a minister in charge of the economy is promoting educational change. It is with an economic development goal behind it. It was to promote entrepreneurship. When other countries are trying to get on top of the universities rankings, Chile is choosing for universities to play a role in driving [entrepreneurial] ecosystems... This is very impressive”.

A number of features appear to underpin the success of these two programmes. Four features stand out in particular. Firstly, participation in

both *MECESUP* and *Engineering 2030* was voluntary – universities could choose whether to apply – and both initiatives provided significant financial support for ambitious reform at the institutional, school or departmental level. As a result, amongst the universities whose funding bids were successful, the levels of engagement by university senior management have been high. Secondly, both programmes were informed and supported by international expertise in their design and delivery. For example, the *Engineering 2030* advisory board brings together international experts in engineering education and technology-driven entrepreneurship. Thirdly, both programmes took a transparent approach to evaluating proposals and apportioning funding, in contrast to previous government interventions of this kind. Finally, for the case of *MECESUP* in particular, universities were given significant autonomy in the design and implementation of educational change. Many interviewees noted the importance of this approach to building cross-faculty support for the reform:

“they were smart to provide incentives without stepping on the autonomy of the universities. This really changed the way [MECESUP] was seen and some universities were really quite visionary in what they tried to achieve”.

It is perhaps for these reasons that all 17 interviewees who expressed a

view on the contribution of *MECESUP* to national educational reform, spoke about its profoundly positive impact. A number of interviewees noted that *Engineering 2030* has taken a more prescriptive approach, explicitly detailing the types of reforms that participating universities must institute. It also specified 70 indicators against which the performance of participating universities would be measured. Some interviewees from participating universities suggested that the level and breadth of assessment involved in *Engineering 2030* imposed a constraint on the coherence and ambition of the changes underway. As one reform leader commented, *“our efforts are spread thin because we have to satisfy so many things – there is a tension between having a real impact and satisfying these indicators”*. It is too soon to determine whether this more directed approach will yield the levels of overall success demonstrated by *MECESUP*. Nevertheless, it is clear that the ongoing *Engineering 2030* programme has engaged a strong and influential group of universities in ambitious and highly innovative reform.

5.2. LEADERSHIP AT KEY ENGINEERING SCHOOLS

Another factor that has undoubtedly underpinned the momentum for systemic educational reform in Chile has been the drive and vision of a number of key engineering schools.

In most Chilean engineering schools, the post of Dean is elected by faculty

vote. A number of interviewees noted that such systems can often give rise to *“an inbreeding relationship in many schools of engineering – people from the same university, same school elected by their mates”*. As a result, *“a business as usual attitude”* can prevail, with little incentive to change the status quo. Despite the constraints of this system, however, a small group of Deans currently holding posts in engineering schools across the country are driving forward a fundamental reform agenda, across and beyond the curriculum. Indeed, one of the most striking elements of the interviews was the evident passion and personal commitment to educational change of this core group of engineering leaders, largely at the Dean or Associate Dean level. This coalescence of leadership – and the ambitious vision for change that has been established – appears to have been critical to driving forward the national reform agenda. As one interviewee noted, *“this transformation has been led by these Deans. A lot of Deans committed to change at the same time is unusual. People who understand the needs of society. It is like the alignment of the planets!”*.

It is also clear that the ambitions articulated by this small group of leaders has had influence beyond their own institutions, establishing dialogues with government, industry and the broader Chilean community about the need for reform in higher education. A significant number of

interviewees pointed, in particular, to the leadership in the engineering schools at UC and UAI, where senior managers had played an instrumental role in shifting expectations and ambitions in engineering education across the country. As one interviewee noted, *“almost every week, there is something in the newspapers [written] by one of the two Deans”*. Many saw their approach as having established a new national agenda and benchmark for university education within and beyond the engineering discipline.

This group of Deans and Associate Deans, however, will only be in post for a limited period. Interview evidence suggested that attitudes amongst other academic leaders in engineering schools – including individuals that may be future candidates for the post of Dean – were often highly sceptical about the educational reforms currently underway. As one national government advisor noted:

“if you don’t maintain this constant momentum of these Deans at the same time, then you will have a new kind of leadership that refuses change. Because there are some kind of leaders that are quiet [for the time being], are not talking...these people do not value and do not agree with some of the transformations at the heart of MECESUP and Engineering 2030”

This suggests that there may only be

a limited window during which fundamental educational reform can be driven forward. It also suggests that careful succession planning for the leadership of engineering schools will be critically important, along with targeted leadership training for high potential early career academics.

5.3. THE NATIONAL IMPERATIVE TO DRIVE TECHNOLOGY INNOVATION

A driving force behind the transformation in Chilean engineering education has been a recognition that the country’s vision for economic growth must be fuelled by a new generation of world-class engineers. This agenda has been explicitly articulated by the Chilean government. As one government advisor commented, *“the Minister of Finance understands that transformation of engineering schools is a must for the development of Chile. At least five of the [government] Ministers in their narratives put engineering as a priority to develop the country”*. This message has been heard and understood across the engineering higher education community. Most interviewees from engineering schools acknowledged that *“the quality of our engineers is good, but we have gaps. We need more innovation capabilities. We need leaders. We need to make this change”*. As one noted *“we have experiences of international companies that see Chile as a good*

place to start R&D, but they do not find enough engineers with good world-class portfolios. That is a pressure for the academy”.

This call to the engineering community to drive the country’s development and growth was described by a number of interviewees as one which builds on a deep-rooted Chilean culture:

“we have a tradition of engineering being an important discipline in Chile... We are called for a more important role in the economy. Chile is a place where there are a lot of challenges – we have a long coast, we have earthquakes, we have mining – engineering is in the mind of a lot of people”.

As the country sought to transition away from its dependence on natural resources and build economic strength around technology innovation, the call from *Engineering 2030* for engineering schools to help deliver a new generation of creative and entrepreneurial graduates was therefore not unexpected or unwelcome. Indeed, this message appears to have resonated with faculty, senior managers and Rectors in universities and engineering schools across the country as well as the wider community. One indicator of this broad-based engagement is the number of engineering schools that have gone on to implement their systemic reforms plans devised during Phase 1 of *Enginee-*

ring 2030 despite being unsuccessful in their bids for Phase 2 funding; in other words, the number of universities that have chosen to self-fund the change. Interviews suggest that a significant number of these institutions are indeed taking forward many of their plans for reform, albeit at a slower pace and on a smaller scale than that originally proposed.

Many interviewees also suggested that the *Engineering 2030* call catalysed a momentum and drive for educational reform that was already growing in many engineering schools across the country: *“there had been a lot of talk about change over the last 10 or 15 years, but after [Engineering] 2030, universities are really doing things differently. They are doing something about it”*.

5.4. EXPOSURE TO EDUCATIONAL IDEAS FROM ACROSS THE WORLD

As many interviewees noted, Chilean engineering education programmes have been based on, and heavily influenced by, traditional educational models from *“the very prestigious universities of Europe and the US”*. Since the 1950s, however, the influence of international educational practice and scholarship on the Chilean engineering curriculum had been limited. Although some strategic relationships with international engineering schools have been sustained over many years, these

typically focused only on research or the training of PhD students. Interviewees noted that a small number of faculty *“who got their PhDs abroad [would] bring some ideas back and create a small cell inside the Faculty”* delivering non-traditional engineering pedagogy. Such educational innovations, however, rarely extended beyond the individual concerned. With limited national networks of support and dialogue in engineering teaching and learning, therefore, many engineering curricula operated in relative isolation from international scholarship and innovative practice in engineering education. In consequence, a number of interviewees suggested that there was *“a complacency”* to engineering education practice at many institutions: *“we had been teaching the same information, in the same way for years – since we were students – and we didn’t see the need to change this”*.

With the introduction of the second phase of the *MECESUP* programme in 2005 came an expectation for international benchmarking. This process required recipient universities to systematically evaluate their entire curriculum in light of observations and reviews of curricula from leading engineering schools worldwide. As noted in Section 3.3, a significant number of Chilean engineering faculty and senior managers started to travel to engineering schools across the world to discuss and observe educational practice, and engineering education experts and practitioners

started to visit engineering schools across Chile to deliver talks and workshops. For many faculty and senior managers, these experiences appeared to have a transformative effect on their attitudes to educational innovation and reform. As one reform leader noted *"normally, you just do what you can see, but [the MECESUP programme] lets you see the possibility to do things better, it opened up our eyes to other ways of teaching"*. Faculty were exposed to some highly innovative models of engineering education and were able to observe how they could be delivered in practice and witness their impact on student learning and engagement. In particular, the educational networks

established by CDIO and LASPAU have been particularly influential, as have the active-learning models developed at Olin College of Engineering and the collaborative learning approaches proposed by Eric Mazur of Harvard University.³⁴ Indeed, over three-quarters of the Chilean faculty and senior managers interviewed for this study mentioned at least one of these networks/approaches/models as key sources of inspiration and/or support for reform.

The international benchmarking process also revealed the extent to which some of the world's leading engineering schools had incorporated student-centred active learning within the curriculum. Indeed, at a number

of Chilean universities, the benchmarking process for both *MECESUP* and *Engineering 2030* was used to quantify the proportion of the curriculum that was devoted to active learning at the world's top 10 to 20 engineering schools from the international university rankings. The recognition that many premier universities worldwide – while maintaining a strong reputation and high research output – were moving away from a purely traditional, theory-based curriculum appeared to send an important message to faculty. In particular, as noted in Case Study 6, it suggested that reform did not necessarily conflict with research reputation and strength.



³⁴ Collaborative Learning, Mazur Group, Harvard University (<http://mazur.harvard.edu/research/detailspage.php?ed=1&rowid=8>)

CASE STUDY 6: UCN

In 2012, the Catholic University of the North (UCN) was awarded a grant of around US\$2m from *MECESUP* to support a major programme of educational change across all 12 departments in the school of engineering. This grant was complemented by a donation of approximately US\$1m from the regional mining industry, situated close to the university in the north of the country. The educational reform focused on five areas:

1. **curricular approach:** to embed active and student-centred learning throughout the curriculum, in order to broaden students' technical and professional capabilities;
2. **degree duration:** to reduce the length of the engineering degree from six to five years, in order to offer consistency with standard university models worldwide;
3. **faculty skills:** to establish a programme of professional development and support in teaching and learning, to underpin the school's transition towards active learning;
4. **levelling-up first year students' capabilities:** to offer dedicated social and academic support to incoming students in order to reduce the disparity of achievement between different student groups in the first year of study;
5. **networking:** to establish effective academic and entrepreneurial networks across and beyond the engineering school.

Across the university, the *MECESUP* award was widely credited with injecting the impetus for systemic education reform: *"change would not have happened without the [MECESUP] grant... but it was not just about the money, it was about the recognition. This was something important for our university"*. However, despite strong support from university senior managers, many faculty remained unconvinced of the underlying need for change and expressed significant concerns that the planned reforms might compromise the rigour and quality of the UCN education. As outlined below, two key factors appeared to play a critical role in allaying these concerns and strengthening the grassroots support for change.

The first factor that influenced faculty attitudes toward the reform stemmed from *"a growing social concern of the professors"*. Like many universities across Chile, the typical duration of a UCN engineering degree was long – around eight or nine years prior to the reform – and dropout rates were high – almost 50% during the first year of study. For a student population that was predominantly drawn from middle-to-low income families and was largely dependent on student loans, the financial burdens were therefore significant. With a growing awareness of the challenges facing the student cohort, an increasing number of faculty began to recognise the benefits of a shorter degree; in turn, attitudes towards the curriculum reform started to change.

The second factor promoting faculty engagement with the reform relates directly to the *MECESUP* grant received by the university and the exposure it brought to good practice in engineering education from across the world. Carolina Rojas Cordova led the reform effort across the engineering school and described how the early years of the *MECESUP* grant supported faculty *“travelling all over the world to see how other professors teach engineering – Barcelona, KTH, Aalborg, Olin College – as well as bringing people to our university”*. She noted both the immediate and lasting impact of these experiences on the outlook of the staff involved:

“the international benchmarking was a very important part of the process. We are located in a place that is far away from everything. We are very isolated. This first year of the project that we spent travelling and bringing people to our university was so important to changing the attitudes of our colleagues”.

Faculty were able to interact informally with innovators and practitioners at the cutting-edge of engineering education worldwide, observing how non-traditional educational approaches could be designed and delivered in practice. In a number of cases, observation of educational innovations at some of the world’s top-ranked institutions – such as MIT, Stanford and UCL – was seen to convey an important message to faculty that non-traditional educational approaches were not necessarily a high-risk activity associated with a ‘dumbing down’ of students’ technical knowledge. The benchmarking process also provi-

ded important links to engineering schools worldwide that were tackling similar issues to those faced at UCN, such as the variable academic profile of incoming students and high drop-out rates in early years of study.

Following three years of benchmarking, curriculum redesign and faculty development, roll out of the educational changes at UCN began in March 2016. The new curriculum is underpinned by project-based learning, with a significant focus on hands-on learning and nurturing students’ intrinsic motivation. Indeed, half of the first year courses – which are delivered to all 700 incoming students by a team of 18 faculty – are now project-based. Later years of the curriculum are designed in semester-long cycles, where a sequence of engineering courses is contextualised by an overarching design project. The final year of study focuses on electives and a capstone project, where students are tasked to solve real problems offered by industry partners. Curricular changes are also supported by new technology-enabled classroom spaces, modelled on the TEAL spaces at MIT. Indeed, from 2016, all calculus and algebra has been taught using active learning methods within these new spaces.

The reforms at UCN have been significant and far-reaching. As the Dean of Faculty, Alex Covarrubias, who now leads the reform process, noted *“this project has been ambitious and challenging. We are sure that it will improve the formation of our students, developing engineers that will be pillars in the development of our country”*.



Ongoing challenges to change



Engineering schools across the world share a number of challenges to educational reform, many of which stem from concerns commonly held by faculty. For example, faculty are often apprehensive that curriculum reform or transitions to student-led learning will result in a 'dumbing down' of students' content knowledge or in a greater time commitment from instructors (Bonwell, 1996, Prince et al., 2013). Interview evidence from this study suggests that these concerns and barriers to educational change are indeed also evident in Chilean engineering schools. Interviews also revealed a number of challenges and barriers to change that appear to be distinct to the national higher education culture and structures, over and above those shared by international peers. These five particular challenges facing Chilean engineering education are:

1. particularly low levels of engagement by grassroots faculty;
2. a national accreditation system that is not perceived to be supportive of innovation;
3. limited cooperation and support between universities;
4. limited collaborations between university and industry;
5. a lack of 'home-grown' expertise in engineering teaching and learning.

Each of these issues is briefly outlined in turn below.

A final factor should also be noted. The study was conducted at a time of

considerable change and uncertainty in Chilean higher education. Almost half of the stakeholders consulted spoke at length about likely government-driven changes to university funding and their potential impact on the progress of engineering education reform across Chile. Although optimism was expressed about the opportunity for establishing greater equality and access to higher education across the country, uncertainty over educational policy and funding clearly presents a significant challenge. The national and political environment appears likely to impact on the trajectory of Chilean engineering education in the future, although the details at this stage are unclear.

6.1. ENGAGEMENT OF FACULTY WITH EDUCATIONAL REFORM

Interview evidence suggests that faculty concerns about educational reform – and the move away from a content-rich, teacher-centred pedagogy towards active, student-centred learning – are particularly acute in Chile. As a result, levels of faculty engagement in curriculum reform appear to be very low. Interview data suggest that this disengagement by grassroots faculty presents the most significant barrier to engineering education reform in Chile.

The majority of the educational changes in Chilean engineering schools have been designed and implemented 'top-down', driven by department heads and Deans. For example, few of the

educational ideas underpinning the new curricula experiences appear to have originated from faculty. Indeed, it is interesting to note that many of the individuals engaged with the CDIO network, particularly in the early years, were reform leaders and senior managers rather than rank-and-file faculty. Although broad consensus appears to have been established between key university leaders and government agencies about the ambition and focus of educational reform in Chilean engineering schools, interviewees pointed to a lack of faculty involvement. Amongst grassroots faculty – particularly those not directly involved in international benchmarking exercises – considerable resistance to adopting non-traditional teaching approaches is still apparent. Establishing more inclusive processes of reform, in which both junior and senior faculty are represented and involved, is likely to be important in catalysing a shift in academic culture. However, with the average age of Chilean engineering faculty being over 55 years – and most having spent their entire career in academia, often in the same institution – such culture may be difficult to change.

Evidence from the interviews suggested that a core group of faculty appear to be particularly disconnected from the transformations underway in their schools:

“there are a lot of teachers saying, “what is my role in all this process?”. Some are afraid because they do not want to be out of date, but they do

not have the leadership or capabilities – or actually the interest – to take part in the transformations”.

Many also appear to hold fundamental reservations about the new vision for engineering education and the assumptions underpinning the design of reformed curricula:

“They do not believe it is possible to produce the same quality of graduates in less than six years. They say academic freedom will be lost with more linkage with industry. They believe that Chilean engineering education needs to develop according to Chilean culture, not copying ideas from Europe or the US”.

A significant proportion of reform leaders spoke at length about the resistance of faculty and the barriers it poses to educational change. In particular, many noted the significant challenges associated with identifying faculty willing and able to deliver new courses based around active-learning pedagogies. For this reason, perhaps, some universities have struggled to enable reform beyond introductory classes in the first year of study and 'capstone projects' in the final year of study. One Associated Dean described the reality of educational change in his engineering school: *“between the first semester and the last year, everything is just the same as it was before”.* He also made clear that faculty resistance would present a significant barrier

to making further inroads into the curriculum.

Some interviewees also described how faculty opposition to reform had resulted in new courses and experiences being introduced as an addition to – rather than as a replacement of – existing components. Such approaches were adopted to counter concerns that cutting back lecture-based content would inevitably lead to a reduction of students' disciplinary knowledge. As a result, concerns were raised by change leaders about the curriculum becoming overloaded, potentially placing a significant burden on students. The experiences of one professor currently leading an educational reform was typical of a number consulted:

“nowadays, we are doing so many things. But there is a tension. We are preaching about how important all of these other experiences are – team-working, innovation, communication skills, problem-solving – but the students are still taking the same big calculus exams... They have to put so much of their time into this. The rigour of the curriculum has not reduced, it has increased, because we are asking the students to do so many more things. Chile is about the rigour. It is one of our seals. But rigour does not mean we have to have everything packed... Maybe

this tension will always exist”.

Similar to countries across the world (Fairweather, 2008, Graham 2015, Fung & Gordon, 2016), the university recognition and reward systems in Chile also present a major challenge to educational reform. During the late 1990s and early 2000s, as part of a broader “*professionalisation of university careers*”, university appointment and promotion systems shifted towards the recognition of research output. Many interviewees noted that these incentive systems often conflict with educational reform, leaving faculty reluctant to devote time and effort to professional development in teaching and learning or curriculum change, for fear it may constrain their career progression. One university leader of an *Engineering 2030*-supported reform summarised the observations of many:

“we have a good design [for educational reform], we write reports and it looks good on paper, but we do not have good implementation... Sixty percent of faculty are waiting for this [focus on educational reform] to pass, waiting for the government to change so they can go back to doing the same as before. Because at the end of the day, we don't have the right motivations in our careers: that is all about productivity in research, not teaching”.

There are, however, some important signs of change, and a number of ‘bottom-up’, grassroots reforms are

emerging from faculty and students in Chile's engineering schools. One particularly interesting example – *Factoria* from UDD, described in Case Study 7 – illustrates how the activities of a small group of staff and students is having a far-reaching impact on the institutional progress of educational reform. A number of universities are also addressing the pedagogical skills deficit, rolling out significant programmes of professional development in teaching and learning to enhance the faculty skill-base and engagement levels in teaching and learning. There is also a growing interest in reshaping career pathways and recognition systems in Chilean engineering schools. For example, some engineering schools are reviewing the potential for establishing a dedicated faculty career pathway in teaching and learning.

CASE STUDY 7: FACTORIA, UDD

The seeds of *Factoria* were sown in late 2012, when a small group of University of Desarrollo (UDD) engineering undergraduates approached one of their professors with an idea to establish a student robotics club. Like many universities across Chile, levels of participation in student societies and clubs at UDD were low, leaving the student engineering community relatively fragmented with few opportunities to engage outside the curriculum. Following this initial meeting, the idea for a new student club quickly evolved into a more ambitious vision – to create a hands-on student-led community that would use technology to solve real problems facing lives and small business in Chile. This small group of *Factoria's* founders were driven, in particular, by a desire to nurture a new innovative generation of tech-savvy Chileans, who could look beyond traditional graduate employment routes and create new technology that would drive forward the national economy: *“there is a real problem in Chile – people think that they can use technology, but not create it. The intention [behind Factoria] was to shift the paradigm in technology and create something in a social environment”*.

A grassroots community quickly took root. It was described as *“a bit of a rebel cause, a bit of a pirate initiative”* and the small group *“started to take space”* across the campus for workshops and prototyping. Early *Factoria* activities focused on the design and delivery of appropriate technologies for regional community partners. For example, one project focused on reducing the air pollution from ovens used by clay pottery handcrafters in a rural town 60km outside Santiago. With a growing reputation across and beyond the university, *Factoria* was soon able to expand its capabilities and reach. The university provided dedicated workshop space, and further investment for tools and machinery was complemented by a grant from MECESUP. In late 2014, *Factoria* opened a second site on the university's Concepcion campus, which again quickly established a strong grassroots community of both students and faculty.

Nicolás Fierro Viedma was a final year Industrial Engineering student during this early phase of *Factoria's* development. He described how he *“came across Factoria when I was looking for a place to study for my final exams”* but became intrigued by the space itself and its potential for *“giving me the tools for putting into practice what I learnt in my studies”*. Nicolás soon became a regular visitor – *“making things, trying*

out the different machines, just for fun” – and became involved with both appropriate technology projects and the growing student entrepreneurial community. He described how these experiences had a lasting impact on his outlook and career ambitions, influencing his decision to join a Santiago-based startup developing low-cost prosthetic hands following his graduation: “I took a different path. I did not want to just have a professional career, I wanted to have an impact on society”.

Today, *Factoria* acts as a hub for a range of student-led activities in technology creation and innovation, attracting participation from staff and students from across campus. *Factoria*’s founding professor, Camilo Rodríguez-Beltrán, also noted its growing prominence as a hub for applied research on campus: “somehow [*Factoria*] matured to a more complex structure that bridges researchers, students and technology; an example of this is that currently 80% of the MSc students in Engineering were regular members during their undergraduate studies of projects in *Factoria*, and *Factoria* hosts interdisciplinary projects from the most diverse sources of research funding in the whole university”. Both the space and activities are managed by the founding professor and a core group of students, known as *Factoria*’s ‘super users’, with strong support from the School of Engineering. It brings together a new open access workshop and prototyping space, opened in May 2016, with a growing number of technology-focused student clubs, research projects, outreach and industry consultancy. It has also established a range of strategic international partnerships, for example with the ‘Little Devices Lab’ at MIT.

What is particularly noteworthy about *Factoria* is its growing influence on the engineering curriculum at UDD. Over time, a small but growing number of faculty has started to reshape elements of their courses in order to make use of the *Factoria* facilities, projects or support activities. These connections with *Factoria* appear to have enabled a gradual shift towards active, problem-based learning in the host courses. Today, 80% of the School’s 1500 undergraduates access the facility in some capacity as part of their formal studies, for example through using the prototyping facilities and/or student-led training workshops as part of a design/build project. José Manuel Robles, former Dean of the School of Engineering, noted that faculty engagement with *Facto-*

ria stemmed, in part, from an acknowledgement of its success in engaging and motivating some of the university’s best and brightest students: “professors can see that this place is different, the club is open, and not segregated. The professors see a new motivation in the students and see how hard they work. Now the professors want to go into the clubs to learn things themselves... In five years’ time, maybe we will have more of these things in the final degree”.



6.2. THE CONSTRAINTS OF NATIONAL ACCREDITATION

Following its introduction in 2002, the Chilean accreditation system was reported by many to have had a broadly positive impact on educational quality in engineering. However, many interviewees suggested that, while accreditation helped to eliminate poor practices during the early years of its implementation, it has since “constrained what is possible in terms of [educational] innovation”.

A number of interviewees suggested that priorities underpinning the national accreditation system mirrored those of traditional Chilean engineering degrees, with stringent requirements for mandatory material that must be covered in engineering science and mathematics. Many interviewees reported that these systems “one hundred percent constrains what we are able to do. It is an old scheme for an old engineering point of view”. The perspective of this engineering professor was typical of many interviewees who have been engaged in educational reform over the past decade:

“accreditation means that the curriculum is very fixed and we don’t have the freedom to choose. The courses we are forced to teach take up so much space in the curriculum. We

don’t have the space to create new courses”.

Perhaps for this reason, there has been a growing interest amongst Chilean engineering schools in securing engineering programme accreditation through the US ABET³⁵ system, which is understood to offer greater flexibility for educational innovation and reform. It also offers “an international stamp of approval on the quality of our education which is important for attracting overseas students”. Two Chilean engineering schools have already taken this route, with UC gaining its last ABET reaccreditation in 2015 and UAI applying for accreditation in 2016.

6.3. LIMITED COLLABORATIONS BETWEEN UNIVERSITIES

Over the past two decades, in countries across the world, national networks of support have played an important role in advancing and informing educational reform in engineering. These include both formal groups and societies (such as AAEE³⁶ in Australia, ASEE³⁷ in the US and 4TU³⁸ in the Netherlands) as well as informal, personal connections between engineering faculty across different institutions. One striking feature of Chilean higher education is the culture of institutional independence, with limited interactions, formal

and informal, between the country’s universities: “the universities are silos and there are no conversations between the silos about anything, they don’t talk to one another, for research or for teaching”. As another interviewee noted, “inside Chile, we don’t work together. We are very competitive. Our closest relationships are with universities outside the country”. This lack of collaboration appears to have imposed a significant barrier to the exchange of ideas and support in engineering education across the country.

One interesting indicator of this restricted inter-institutional connectivity was captured during the interviews for this study. All interviewees were asked to identify examples of best practice in engineering education from across the country. It was striking to note that, apart from an appreciation of practice at UC and UoCH, most interviewees were largely unaware of engineering education approaches or reform activity beyond their own institution.

It is clear that the competitive approach taken by the Chilean government to higher education funding – where universities bid against one another for a limited pool of funding – has reinforced this lack of trust and collaboration between institutions. A number of interviewees noted that “people don’t want to work with other universities in case their ideas are stolen and they lose their competitive edge

35. Accreditation Board for Engineering and Technology (<http://www.abet.org/accreditation/>)

36. Australian Association for Engineering Education (<http://www.aee.net.au>)

37. American Association for Engineering Education (<https://www.asee.org>)

38. 4TU Centre for Engineering Education (<https://www.4tu.nl/en/education/>)

[in future funding rounds]". One Dean commented that, "in Chile, it is difficult for universities to work together, it is a cultural thing. It is such a competitive system [for funding], people do not work together". With most Chilean faculty remaining in the same institutions for the duration of their academic career, such a culture will be hard to break.

Despite these challenges, however, there is no doubt that *Engineering 2030*, which offered incentives for participating universities to form consortia, has helped to stimulate collaborations between institutions in teaching and learning. Interviews made clear that a number of these consortia, although challenging to manage, are helping to initiative new communities of practice and relationships of trust between Chilean universities.

6.4. LIMITED COLLABORATIONS WITH INDUSTRY

The past decade has seen a growing national debate on the need for change in Chilean engineering education. Both government and, increasingly, universities have played an active role in driving forward a reform agenda. One sector, however, has been notable by its absence from many of these national conversations: Chilean industry. This lack of engagement contrasts sharply with experiences in other countries across the world where industry has played an important role in articulating the changing competencies required of engineering graduates in the 21st

century and underlining the need for educational reform (NAE, 2004, Royal Academy of Engineering, 2007, EEF, 2014, King, 2008).

A number of interviewees, particularly those from senior university positions, suggested that this lack of support from the Chilean engineering industry reflects the restricted nature of the collaboration between universities and industry in Chile: "the relationship between universities and industry is an economic transaction – everything is related to money. It is not a partnership". As a result, many Chilean students have limited and little exposure to industry or authentic problems during their studies: "we have a lot of projects [in the curriculum] but the projects are all very simple, they are all 'toy' projects, it is not the real world".

There are, however, promising signs of change, with a small but increasing number of engineering schools working with industry to offer students authentic engineering problems and projects, as outlined in Section 3. This practice has undoubtedly been reinforced in recent years by *Engineering 2030*.

6.5. LIMITED HOME-GROWN EXPERTISE IN TEACHING AND LEARNING

International benchmarking processes have played an invaluable role in inspiring and shaping educational reform in Chile's engineering schools. However, a review of recently implemented programmes and courses

would suggest that many have drawn heavily on these international exemplars in their design and delivery. Adopting an educational experience that has proven successful elsewhere clearly offers important advantages, but it also carries risks: most notably the fact that the evidence underpinning its design is likely to have been taken from a very different culture, context and student demographic.

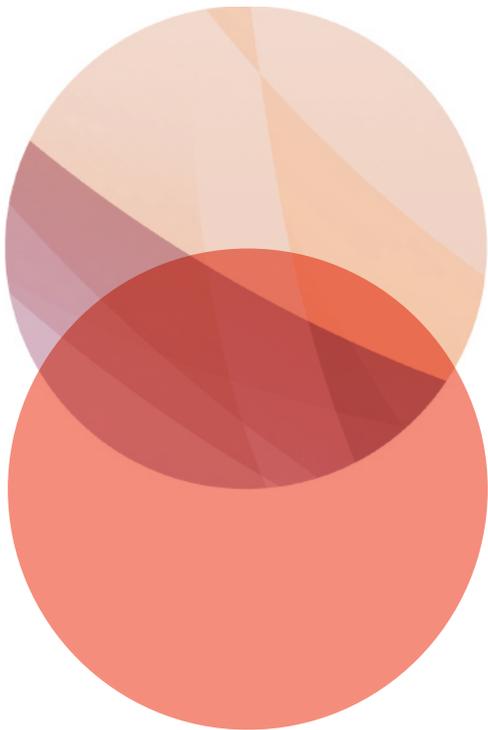
This suggests that Chile's engineering schools would benefit from greater 'home-grown' expertise in engineering education and educational scholarship. Such research-based activity would help

to establish bespoke, evidence-based innovations that reflect the Chilean educational environment. It would also place the country in a stronger position to further raise its profile as an emerging international presence in engineering education. In recognition of these issues, a growing number of Chilean engineering schools have established research groups in engineering education in recent years. These include the *Center For Education Research in Engineering and Sciences* (CiD-iC) at UTFSM, the *Engineering Education Research Group* at UC and the *Engineering Research Group* at UCSC.



Pontifical Catholic University of Chile (UC)
Solar Car

Concluding comments



This report has provided a snapshot review of engineering education reform in Chile, show-casing examples of good practice from across the country. In particular, it has highlighted the significant impact of two government interventions – *MECESUP* and *Engineering 2030* – in stimulating and supporting educational change, underpinned by strong leadership and engagement by many engineering schools across the country.

Given these important drivers of change are in place, it is worth noting that many of the Chilean faculty interviewed for the study suggested that the scale and pace of national change in engineering education were relatively modest: *“I don’t really see much happening. People are still very conservative”*. To a certain extent, these observations are valid; the vast majority of Chilean engineering degree programmes are still six years or more in length and much of the curriculum and pedagogy in many engineering schools have changed little in over 50 years. Indeed, many of the educational innovations, while strong and effective, would not be remarkable on an international stage. However, such assessments may fail to do justice to Chile’s achievements. Comparing **progress** in Chile over the past 10 years with other countries, the scale and pace of change has been impressive. Engineering education reform in most countries and most institutions worldwide could

be characterised by a series of incremental steps – the integration of capstone projects, a move to outcomes-based assessment, the establishment of student maker-spaces, etc. – which have taken place gradually, over many decades. Some countries, such as Denmark, Sweden and Australia, have arguably progressed further with a reform agenda, but the pace of change has been no more rapid. In addition, although some exceptional engineering education practice exists worldwide, these pockets of good practice often represent outliers when compared to the rest of the country or institution. What is remarkable about the Chilean reform is how far the country as a whole has moved in little over ten years – from a landscape almost entirely devoted to lecture-based delivery of traditional engineering content to broad-based engagement with curricula and pedagogical reform across a core of the country's most respected universities. Indeed, in a country of less than 18 million inhabitants, to have over 15 engineering schools reporting to be engaged in systemic educational change is extraordinary.

Of course, significant progress still needs to be made – not least in reducing the length of engineering degrees – and most Chilean engineering programmes do not yet compete with the best programmes across the world. The country also faces challenges that must be

addressed, such as nurturing engagement and support for grassroots change amongst engineering faculty, establishing informal networks of support between universities, supporting the development of research expertise in engineering education and connecting industry with the engineering education agenda. Great care must also be taken to monitor and evaluate the ongoing reforms, to ensure that the aims are being achieved and momentum continues beyond the current funding cycle for *Engineering 2030*. However, if maintained, the pace of national change will help to position Chilean engineering education as a force to be reckoned with in the decades to come.

APPENDIX A UNIVERSITY ACRONYMS

UC	Pontifical Catholic University of Chile
UAI	Adolfo Ibáñez University
UBB	University of Bio Bio
UTFSM	Federico Santa Maria Technical University
UoCH	University of Chile
UDEC	University of Concepción
USach	University of Santiago, Chile
PUCV	Pontifical Catholic University of Valparaíso
UDD	University of Desarrollo
UCN	Catholic University of the North
UCSC	Catholic University of the Most Holy Conception
UFRO	University of La Frontera
U. Maule	Catholic University of the Maule

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