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Achieving excellence in engineering education: the ingredients of successful change

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Grateful thanks

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Foreword

> *No profession unleashes the spirit of innovation like engineering. From research to real-world applications, engineers constantly discover how to improve our lives by creating bold new solutions that connect science to life in unexpected, forward-thinking ways. Few professions turn so many ideas into so many realities. Few have such a direct and positive effect on people's everyday lives. We are counting on engineers and their imaginations to help us meet the needs of the 21st century.*
>
> Changing the conversation – messages for improving public understanding of engineering, National Academy of Engineering, 2008

Engineering is vital to successful, sustainable civilisation. So much rests on the shoulders of future generations of engineers that we must give them the best possible foundation to their professional lives.

This means ensuring that engineering graduates can apply theoretical knowledge to industrial problems as well as exhibit theoretical understanding, creativity and innovation, team-working, technical breadth and business skills. To do this, engineering degree programmes must keep pace with the changing requirements of industry, with much more interaction between departments and industry.

We call this *experience led engineering education* and The Royal Academy has defined this in a series of reports going back to 2006. This latest report goes beyond asking *what* to change or *why* and asks *how* successful and <u>sustainable</u> change has been achieved by engineering faculty around the world. It is essential reading for everyone responsible for the education of the next generation of engineers.

Professor Edward Crawley FREng
President
The Skolkovo Institute of Science and Technology

Dr David Grant FREng
Vice Chancellor
Cardiff University

Executive summary

A series of reports from The Royal Academy of Engineering (The Royal Academy of Engineering, 2006, 2007, 2010) has demonstrated that change in undergraduate engineering education is urgently needed to ensure graduates remain equipped for the new and complex challenges of the 21st century. However, the necessary transformation in the structure and delivery of undergraduate provision has yet to take place across the sector. There is a growing appreciation that the slow pace of change reflects the difficulties of catalysing and sustaining educational reform within engineering departments and schools. The case for reform is recognised; the challenge is to make it happen. The pressing issue for engineering education is not *whether* but *how* to change.

The report turns the spotlight on this issue. It examines how positive change can be achieved across the engineering curriculum, looking specifically at how reform can be initiated, implemented and sustained within engineering departments and schools.

The report draws on the experiences of those involved in major programmes of engineering education reform across the world with the aim of distilling the common features of success and failure. A two stage study was conducted between January and October 2011. Firstly, interviews were conducted with 70 international experts from 15 countries, each with first-hand experience of curriculum change in engineering. The interviews provided insight into a wide range of examples of curricular reform from across the world, offering a high-level view of the features associated with successful and unsuccessful reform. Secondly, six examples were selected from those identified through the expert interviews to investigate in detail how significant educational reform can be achieved. The six case studies are all highly-regarded, selected to provide a spectrum of drivers for reform, change strategies, levels of ambition, geographical locations and stages in the change process. A further 117 individuals were consulted for these case studies.

The study identifies four common features of successful, widespread change that appear to be largely independent of geography or institution type. These are discussed in turn below.

Firstly, successful systemic change is often initiated in response to a common set of circumstances. In contrast to course-level (in the UK, *module* level) changes, which are often driven by persuasive pedagogical evidence or national calls for a new 'breed' of engineer, successful widespread changes are usually triggered by significant threats to the market position of the department/school. The issues faced are strongly apparent to faculty and, in some cases, university management have stipulated that a fundamental change is necessary for the long-term survival of the programme and/or department. Typical issues include problems with recruitment, retention and employability. The urgent and fundamental nature of these problems creates both a widespread acknowledgement that educational change is unavoidable, and a collegiality and common purpose amongst faculty in achieving the curriculum-wide reform. These conditions appear to vastly increase the chances of systemic reform being both successfully implemented and sustained. A number of other common contextual factors are shared by successful change programmes. For example, they are much more likely to involve faculty with industry experience and/or newly-hired faculty, often replacing those retiring. Also, in a surprising number of cases, the leaders of successful curriculum-wide change have experienced failure in prior attempts to make isolated changes at the course level, from which they concluded that "*change needed to be radical and widespread for it to stick*".

Secondly, a number of common features are apparent in the educational design of successful programmes of change. Success appears to be associated with the extent to which the change is embedded into a coherent and interconnected curriculum structure. The study identified numerous examples of ambitious reform that had ultimately failed due to their curricular isolation and reliance on one or two faculty members. Almost without exception, successful and sustainable change starts with a fundamental assessment of the curriculum-wide goals and involves a high-level re-alignment of the entire curriculum structure in which a cross section of faculty are involved. This successful approach to educational design appears to be independent of the scale of change undertaken. Indeed, most successful 'curriculum-wide' changes typically only involve the creation of a relatively small number of new courses – usually less than 20% of the curriculum. What distinguishes them, however, is the extent to which the changes are interconnected within a re-designed coherent curriculum structure with multiple horizontal and vertical dependencies. The vast majority of successful change programmes considered in this study have also sought to create a new 'brand' for their educational approach, and one that aspires to set a benchmark for national or international engineering education practice. This status, as a potential world-leader, is one that supports continued faculty engagement with the reform process.

Thirdly, the department appears to be the engine of change, with the sustained commitment of the Department Head being a critical factor in its success. Regardless of the scale of the planned change (from a school-wide effort to a small cluster of courses), the successful changes were consistently identified as those that had taken a department-wide approach to the reform. For example, amongst the school-wide reforms considered in this study, long-term successful curricular changes are confined to individual departments, with very limited diffusion of good practice outside their boundaries. The pivotal role played by the Head of Department in successful change is also a major finding of the study. Almost without exception, successful changes are energetically supported by the Department Head, who invariably is also the leader or co-leader of the change. This individual is typically internally appointed and very highly regarded in both their research and teaching activities. A long-standing trust in the Department Head amongst a core of faculty often leads to a widespread belief that their efforts in the educational change would be valued and a belief that this individual would "*fight our case*" during promotions procedures.

Finally, the study highlights significant challenges associated with sustaining change, with the majority of reform endeavours reverting to the *status quo ante* in the years following implementation. Indeed, even amongst those changes that are successfully maintained, many have encountered significant problems around 5–10 years after the graduation of their first cohort of students. Most experience a gradual course-by-course 'drift' back to a more traditional curriculum. These issues often stem from a growing sense amongst faculty that the new curriculum is no longer 'cutting-edge' and/or an influx of newly-appointed faculty who did not experience the threat that precipitated the reforms. The critical test of the sustainability of an educational reform is whether it continues beyond a university restructuring or changes to senior management. The change programmes that appear to be most resilient in these conditions are those that involve: a cross-section of faculty in the delivery of the reformed courses, a well-disseminated impact evaluation of the change and an on-going focus on educational innovation and reinvention.

The study highlights the significant effort that has been devoted to engineering curriculum reform across the world. It also underlines the difficulties experienced by the 'lone champions' who are currently driving reform in engineering schools and departments across the world, where changes often prove limited and short-term. The evidence points instead to the importance of departmental leadership and widespread faculty engagement in a process of reform which is informed, coherent and ambitious. Distilling the strategies employed in successful change endeavours, the study offers some recommendations for the consideration of engineering schools and departments wishing to embark on curriculum reform. It closes with three recommendations for the engineering education community, to help to ensure that curriculum reforms stand the best possible chance of achieving a positive and sustainable change.

Acknowledgements

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Dr Ruth Graham

Contents

1 Introduction

1.1 Background

> *"Engineering today is characterised by both a rapidly increasing diversity of the demands made on engineers in their professional lives and the ubiquity of the products and services they provide. Yet there is a growing concern that in the UK the education system responsible for producing new generations of engineers is failing to keep pace… The structure and content of engineering courses [programmes] has changed relatively little over the past 20 years".*
> (The Royal Academy of Engineering, 2007)

A series of reports from The Royal Academy of Engineering (The Royal Academy of Engineering, 2006, 2007, 2010) demonstrates that change in undergraduate engineering education is urgently needed to ensure graduates remain equipped for the new and complex challenges of the 21st century. However, the necessary transformation in the structure and delivery of undergraduate provision has yet to take place across the Higher Education sector. The engineering curriculum in most institutions has proved resistant to change and this problem is not confined to the UK:

- **From the US** – *"…we are sobered by two realities: first, that scattered interventions across engineering education over the past decade or so have not resulted in systemic change, but rather only in isolated instances of success in individual programs, on individual campuses; and second, that the disconnect between the system of engineering education and the practice of engineering appears to be accelerating."* (National Academy of Engineering, 2004)
- **From Australia** – *"… the engineering curriculum has been slow to respond and while there has been some reform over the past 15 years, the educational model we use is still not much different from that of 30 years ago, and while the pace of change in the world has increased significantly, the pace of change in engineering education has been far too slow".* (Institution of Engineers, Australia, 1996)

There is a growing appreciation that the slow pace of change reflects the difficulties of catalysing and sustaining systemic educational reform within engineering departments and Schools. The case for change is recognised; the challenge lies in making it happen. In other words, the pressing issue for engineering education is not whether to change but how to change.

1.2 Focus

This study focuses on the conditions and mechanisms for achieving positive and sustainable change in the core undergraduate engineering curriculum. Educational design is clearly a critical element of successful change; *what* changes should be made are therefore of fundamental importance. However, this report is primarily concerned with *how* successful change can be initiated, implemented and maintained.

In most engineering departments, innovative approaches to teaching and learning are typically only found at the margins of the undergraduate curriculum, with their development and continuation resting on a few highly committed individuals. In contrast, this study looks at strategic, systemic changes, within a Department or School of Engineering, that affect the mainstream education of a large proportion of the student cohort and the factors that optimise the success and sustainability of such a reform. It seeks to identify successful change strategies that have produced long-term positive outcomes as well as highlight common pit-falls that can sink programmes of curricular reform.

The study draws on international knowledge about educational change in engineering, supported by interviews with international experts and additional evidence-gathering from selected case studies. Evidence has been gathered through consultations with 187 individuals from across the world, of which 123 were formal one-to-one interviews. Although international in its view, the study focuses particularly on the US and UK.

The study builds on three pivotal reports published by the Royal *Academy of Engineering – Educating Engineers for the 21st Century* (Spinks et al 2006, RAEng 2007) and *Engineering Graduates for Industry* (RAEng 2010) that called for major changes to the engineering curriculum.

1.3 Approach

The report is informed by three sources of information, gathered between January and October 2011:

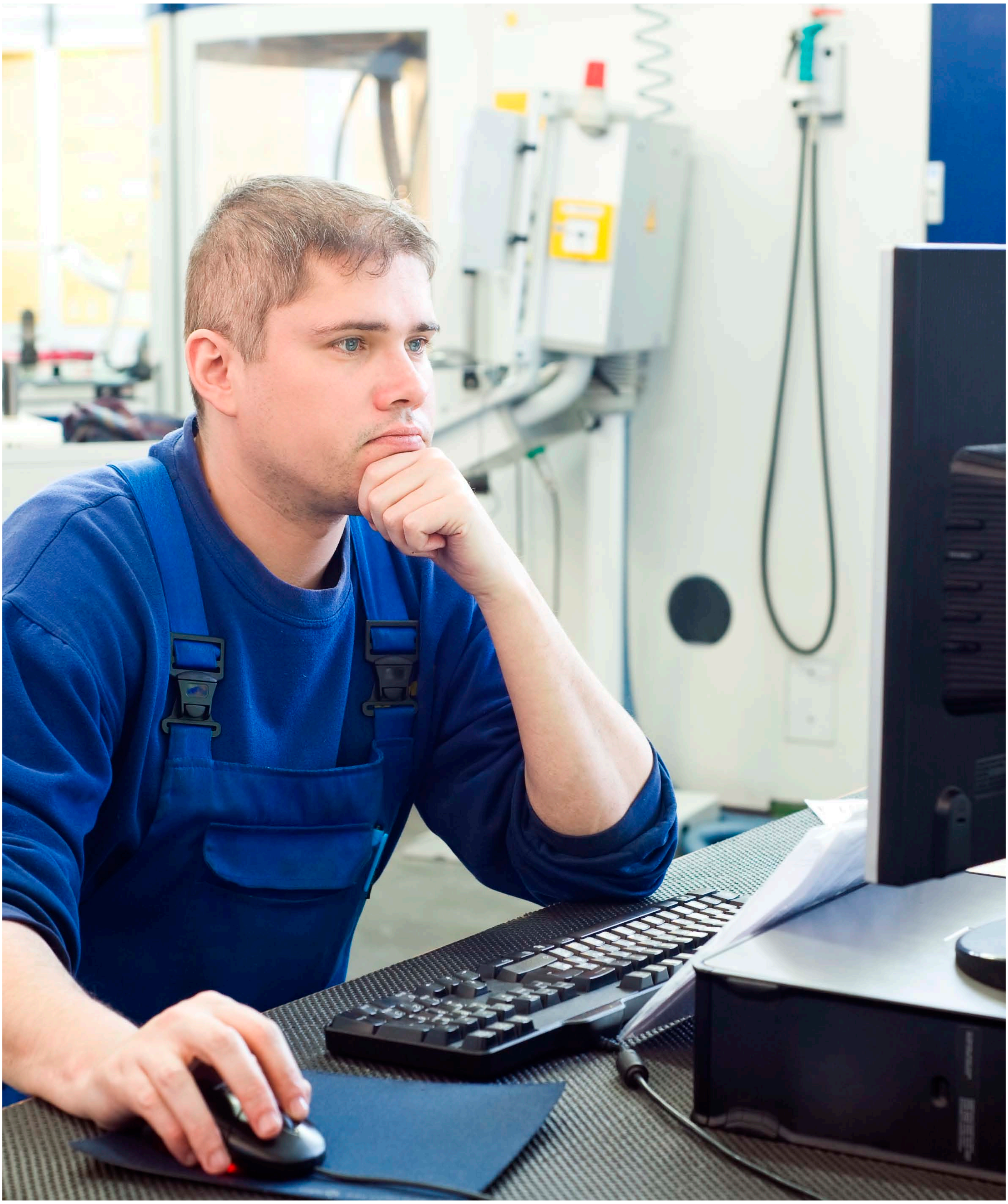
- **Phase 1: snap-shot review of the literature on educational change in engineering.** A summary is provided in Chapter 2.
- **Phase 2: interviews with international experts and practitioners.** Expert evidence was captured from 70 individuals from 15 countries across the world[1], drawing on their perceptions, experiences and future forecasts for educational change in undergraduate engineering education. The interviews focused on the current climate for educational change at a national level, key barriers to establishing and implementing reform efforts and the critical ingredients for successful and sustainable reform. The interviews targeted: (i) research experts in the field, (ii) those with experience of leading educational change in engineering, (iii) those with a national or international policy view of engineering education, and (iv) observers to academic reform efforts, such as industry advisors. A summary of insights from the interviews is presented in Chapter 3.
- **Phase 3: case studies investigations.** Six programmes of educational reform in engineering were identified from the expert interviews, and a diagnostic undertaken of the critical conditions and catalysts for change in each case. The selected case studies are from the US, UK, Australia and Hong Kong. A total of 128 individuals were consulted for the case study investigations, of which

1 It should be noted that 11 individuals contributed both to the interviews in Phase 2 and the case studies in Phase 3

64 were formal one-to-one interviews, typically one hour in duration. Each case study investigation drew on interviews with between 8–17 individuals who led, participated in, managed, observed or were affected by the change, to undertake an analysis of the factors critical to the programme's success. These six case studies are presented in Chapter 4.

Chapter 5 provides a summary of the study outcomes, presenting an overview of the critical common elements in successful programmes of educational change in engineering.

Unless directly quoting from interviewees in the study, all terminology used in this report is based on US convention, where, for example, *faculty* refers to departmental academic staff and *course* refers to a discrete credit-bearing unit within a degree programme.



2 Summary literature review

This chapter provides a summary review of the literature in educational change in engineering. The review looks in turn at the development of research on change in engineering education (2.1), how curriculum change is typically approached in practice (2.2), alternative change strategies (2.3), the drivers for making a change (2.4), the critical features of success and failure (2.5), the role of academic culture and existing rewards procedures (2.6) and how the impact of change is measured (2.7).

The key messages are (i) the dearth of research on strategies for successful, systemic change in engineering education, (ii) the dominance of the 'diffusion of innovation' educational change model in the literature, despite some concerns about its applicability to curriculum reform, and (iii) the lack of high quality evidence to evaluate the impact of engineering curriculum change.

2.1 Origins and focus of research in the field

Educational change in engineering is a relatively new field of research. It has its origins in the 1980s, in the drive to increase student numbers and/or diversity in the Science, Technology, Engineering and Mathematics (STEM) undergraduate body (Godfrey, 2009 and Seymour, 2001). This field of research was later shaped by a desire to increase the talent pool in the engineering education pipeline and the need to prepare engineering graduates to meet the complex industrial and societal challenges of the 21st Century (King, 2008, Jamieson and Lohmann, 2009, Spalter-Roth et al., 2007).

The majority – probably 80–90% – of the research in engineering education change has been undertaken in the US. This is largely a product of the US approach to funding educational innovation in the sciences in recent decades, through the National Science Foundation (NSF). During the 1990s and early 2000s, the NSF invested over $200m in the Engineering Education Coalitions Program, targeted at 8 university coalitions, to "*foster broad-based, rapid, synergistic, and collaborative change*" (Coward et al., 2000). Although the coalitions resulted in local improvements at the host institutions, they "*did not lead to the comprehensive and systematic new models for engineering reform that were expected*" (National Science Board, 2007). For many, the failure of coalitions to catalyse wider change across the sector was a consequence of the model of change on which the Coalition Program was based. Drawing on Rogers' *diffusion of innovation* model (Rogers, 2003), it was assumed that "*if a group of institutions developed, implemented, assessed, and institutionalized a set of innovations with extensive funding, then these innovations would be rapidly adapted and adopted across a broad spectrum of institutions without significant funding*" (Borrego et al., 2007). In other words, the focus of effort was directed on developing and proving the efficacy of the innovation, because, it was assumed, the wider adoption will take care of itself, once the results are disseminated. It is a criticism levelled at many of the change strategies proposed in the engineering education literature, which are similarly based on the assumption that the "*demonstrated superior efficacy of an alternative learning environment will motivate faculty to change*" (Froyd et al., 2000). As more recent research notes, evidence of the efficacy of an educational innovation is "*necessary but not sufficient*" to trigger the wider adoption of such approaches (Borrego et al., 2010, Dancy and Henderson, 2010, Seymour, 2001, Froyd et al., 2006). Indeed, Kezar (2009) notes that, although diffusions of innovation models "*sometimes work with individual change agents...[they]… do not translate well into larger scale change efforts*".

The fact that the prestigious Coalition Program was based on a *diffusion of innovation* model appears to have heavily influenced wider research on engineering education change in the US. Much of the scholarship, itself often funded directly or indirectly via the NSF, has focused on the extent to which proven educational innovations in engineering are adopted by faculty members beyond the developer's course, department or institution (Spalter-Roth et al., 2007, Borrego et al., 2010, Dancy and Henderson, 2010). This model of educational change – where innovations naturally 'diffuse' between faculty members – has left unchallenged the assumption that influencing the beliefs, priorities and behaviours of the *individual faculty member* holds the key to successful and sustainable educational reform. Such an assumption is at odds with the wider literature on change in higher educational more generally, where the *department* as a whole is seen as the critical unit for change (Trowler et al., 2003, Weiman et al., 2010).

Outside the US, research on engineering education reform follows a much less coherent direction. However, three key distinct areas are commonly considered: (i) evaluation of change efforts at particular institutions (e.g. Pundak and Rozner, 2008, Wilson-Medhurst et al., 2008, Molyneaux et al., 2010), (ii) successful strategies for the adoption of problem-based learning (PBL) within elements of the curriculum (van Barneveld and Strobel, 2009, de Graaf and Kolmos, 2007), and (iii) the consideration of the organisational culture in engineering and its impact on the change process (Godfrey and Parker, 2010, Merton et al., 2004).

2.2 Critique of current change activities

Critical examinations of current approaches to educational reform in engineering appear to be limited. Outlined below is a summary of available evidence, looking in turn at the *scale*, *nature* and *extent* of changes that have occurred in recent decades.

Firstly, the literature makes clear that current models of innovation and curricular change are typically small-scale, 'stand-alone' and do not impact wider departmental, institutional or national practice (Heywood, 2006). In consequence, these innovations are typically lost when the faculty member initiating the change moves on (Fisher et al., 2003), because their colleagues are unwilling "*to invest the time to teach the course in the new manner in part because the time commitment was greater than for traditional lectures*" (Fairweather, 2008). This model of change is seen to reflect the autonomy traditionally enjoyed by faculty, enabling them to institute change in their own programme. Thus, change "*arises from the dissatisfaction of an individual faculty member with an element of student performance or participation*" with little or no scientific rigor in its development or impact assessment (Froyd et al., 2000, Jamieson and Lohmann, 2009). Those examples of ambitious department- or School-wide innovation most commonly cited in the literature – such as Olin College of Engineering in the US (Somerville et al., 2005) or Aalborg University in Denmark (Kolmos et al., 2004) – tend to have been designed from a blank slate rather being the product of an educational transformation from a more traditional curriculum. As such, they do not offer insights into the *change process* at the systemic level.

Secondly, there is a small literature focused on the particular topics/areas that have been the focus of past or recent change efforts. Again, the vast majority of this research is US-based. For example, a 2001 study analysed the changes in engineering education over the preceding decade, as viewed by 27 senior figures in US engineering industry, academia and professional bodies (Bjorklund and Colbeck 2001). The authors identified five key areas where change has occurred: "*the incorporation of design throughout the curricula; an emphasis on effective teaching; the influx of computer technology in the classroom and beyond; the need for a more broad-based curricula; and a new interest in assessment due in large part to ABET 2000 accreditation criteria*". A more recent survey of 197 US engineering department chairs looked at the levels of both awareness and adoption of established engineering education innovations such as *artefact dissection* or *summer bridge programs* (Borrego et al., 2010). The study identified high levels of awareness (82%) of the innovations by the Heads of Department, but relatively low levels (47%) of adoption within their departments. These results closely mirror the output from similar US-based studies on innovation in physics undergraduate education (Dancy and Henderson, 2010, Henderson and Dancy 2009).

Thirdly, the literature review points to the dearth of research focused on the extent to which widespread change has *already* occurred across the engineering education sector. One exception is the Engineering Change study (Lattuca et al., 2006), which studied the impact of the ABET EC2000 outcomes-based accreditation standards on US engineering education practice between 1994 and 2004. Over this 10-year period, the study pointed to an improvement in US engineering graduates' "*understanding of societal and global issues, their ability to apply engineering skills, group skills, and understanding of ethics and professional issues*".

There appears to be limited evidence on national differences in approach to educational change. However, an international, cross-disciplinary study of educational excellence in research-intensive universities concluded that "*no systematic differences [were] found between departments in universities in the UK and Australia, Europe and North America. Their research-intensiveness was their dominant characteristic, not their national context.*" (Gibbs et al., 2009)

2.3 Models and strategies for change

A critique of models of curricular change has been the topic of debate in the engineering education literature (Froyd et al., 2000, Smith et al., 2004, Fisher et al., 2003, Clark et al., 2004, Walkington, 2002). Seymour (2001) provides a well-regarded categorisation of change theories typically used within STEM educational reform. She also comments that "*in reform efforts, the theory or theories that underwrite the chosen forms of actions often remain unstated*". Probably the most highly-regarded analysis of the change theories adopted within higher education is provided by Kezar (2001), who draws a clear distinction between systems change (typically externally-driven and occurring across the sector, such as accreditation changes) and organisational change (occurring within a single institution).

The evidence in the engineering education literature suggests that successful educational reform is often associated with a combination of 'top-down and bottom up' change (Seymour et al., 2011, de Graff and Kolmos, 2007, Walkington, 2002, Heywood, 2006). At the broader higher education level, Elton (2002) identifies the combination of top-down and bottom-up pressures as the "*most important feature of successful change in universities…with the top down being facilitative and the bottom up innovative*". He also adds "*even if the innovation comes originally from the top, it may be wise to keep that secret*".

More recent literature on educational change in engineering has often drawn on the model for change developed by Kotter (1996), where the process of reform is viewed as a series of 8 discrete stages. A summary of the Kotter change model is provided in Figure 1, with the particular context for reform in engineering education provided in the right-hand column for each stage, as proposed by Froyd et al. (2000).

Although some feel that Kotter's approach is too prescriptive, the strong emphasis on establishing both urgency and constituency buy-in is seen to be a critical, and often overlooked, element of change in engineering education (de Graff and Kolmos, 2007). For some, Kotter's approach provides a particularly robust model for curriculum change within engineering departments because it "*focuses on a process of building a coalition around a recognised need rather than efforts of individual faculty and/or the sufficiency of research data*" (Froyd et al. 2000).

There is also some debate in the engineering education literature about which stakeholder groups, in particular, should be engaged in order to most successfully effect change. Most existing educational interventions and reform strategies in engineering typically engage those faculty who are already committed to improving and developing their educational provision. In contrast, Fairweather (2008) argues that the greatest positive change in STEM education will be produced by focusing efforts on those faculty members whose only current educational approach is lecturing to "*use any form of active or collaborative instruction*", rather than continuing to support existing innovators. Others argue that successful educational change should begin with affecting a shift in the attitudes and behaviours of the students rather than the faculty (Korte and Goldberg, 2010). For some, however, systemic and sustainable change in engineering education can only be possible – and will only be greater than the sum of each individual faculty member's contributions – if a culture of collective responsibility can be developed across all faculty (Fisher et al., 2003).

1. Establish a sense of urgency	1. Establish need and energy for a curricular change
2. Form a powerful guiding coalition	2. Gather a leadership team to design and promote the curricular change
3. Create a vision	3. Define and agree upon new learning objectives and a new learning environment
4. Communicate the vision	4. Discuss the new objectives and environment with the college and revise based on feedback
5. Empower others to act on the vision	5. Implement new curriculum using a pilot, if necessary
6. Plan for and create short-term wins	6. Conduct a formative evaluation of the program, investigating strengths and weaknesses of the current implementation, and indicators of short-term gains
7. Consolidate improvements and sustain the momentum for change	7. Decide how the new approach may be used for the entire college and prepare an implementation plan
8. Institutionalise the new approaches	8. Prepare faculty and staff for the new implementation, implement, and follow up with improvements

Figure 1. Kotter's change model (left) set in the context of engineering education reform by Froyd et al. (right)

2.4 Drivers for change

The vast majority of the literature describes the drivers for change to engineering education either at the level of the global/national need (Jamieson and Lohmann, 2009, King, 2008, Duderstadt, 2008) or on the motivations of the individual faculty member (Cady et al., 2009, Dancy and Henderson, 2010). The drivers for strategic change across a department or School are less often discussed in the engineering education literature.

In their evaluation of change efforts to PBL in engineering education, van Barneveld and Strobel (2009) assert that, where the drive for change in medical education appears to be bottom-up, relating to student and faculty dissatisfaction, those in engineering and business tend to be top-down, stemming from dissatisfaction among employers groups. They also contend that drivers for educational change appear to be grounded in issues that are "*profession-specific rather than being geography-specific*". Evidence from the wider literature on change in higher education (Gibbs et al., 2009*)* found that "*experiencing a significant problem or challenge (such as a negative external review or even the threat of removal of professional accreditation) was found to be virtually essential if a process of change was to be adopted*". It is interesting to note that this relationship between a strong external trigger and planned systemic change is also evident at the primary and secondary education levels. A recent report looking at the most improved schools from across the world (Mourshed et al., 2010) found that "*the impetus required to start school system reforms – what we call ignition – resulted from one of three things: the outcome of a political or economic crisis, the impact of a high-profile, critical report on the system's performance, or the energy and input of a new political or strategic leader*". For some, however, "*the strongest motivation for an engineering faculty member at a research university to be interested in STEM innovation is the prospect of saving time for research*" (Porter el al., 2006).

2.5 Critical features of success and failure

The key features of successful change emerging from the literature are outlined below.

- ***Leadership, communication and vision.*** The importance of strong leadership with a clear and well communicated educational vision is repeatedly emphasised in the literature (Gibbs et al., 2009, Walkington, 2002). Indeed, "*one of the main reasons that changes do not occur is that people fundamentally do not understand the proposed change and need to undergo a learning process in order to successfully enact the change*" (Kezar, 2009). Seymour et al. (2011) point to what they term "*radicalised seniors*" as key champions of reform within universities or engineering Schools "*in publicly promoting educational improvements, legitimating their uptake, protecting younger faculty reformers from negative consequences of their work, and using their power and influence to leverage change at the national, institutional, departmental, and disciplinary levels*".

- ***Faculty development.*** Participation in faculty development programmes appears to influence an individual's openness to implementing new teaching and learning approaches in the classroom (Henderson, 2008). For example, a recent study of engineering faculty identified that "*those who had some formal preparation in teaching were significantly more likely to report using active learning techniques and activity-based assessments*" (Lattuca, 2011). Such experiences, however, appear to be much more effective when they are delivered within the engineering context, rather than from a cross-disciplinary university centre (Felder et al., 2011).

- ***Faculty engagement.*** Developing a strong sense of faculty ownership of the reforms is identified as critical for successful change (Elizondo-Montemayor et al., 2008). In particular, the development of a "*collegial commitment to student learning*" (Ramsden et al., 2007) is seen to be an important element in developing an effective and coherent educational programme (Fisher et al., 2003). The development of such communities, however, can often come at the cost of faculty autonomy and independence (Newton, 2003). For some, the key to successful and sustainable reform lies in breaking the direct responsibility between an individual faculty member and any new or innovative courses. As Gladding (2001) comments, it is essential to share both the "*pain and gain*" of these developments and reduce the reliance on "*teaching heroes*" who are liable to becoming burnt-out. One strategy proposed for distributing the burden of developing and maintaining innovative approaches is the implementation of 'teaching teams' (Hadgraft, 2005, Crosthwaite et al., 2001).

- ***Resources and time.*** Insufficient resourcing and/or time are seen to be a key barrier to successful change (Henderson and Dancy, 2007). Indeed, a study of the barriers to change among science faculty found that *resources*, *time* and *turf conflicts* were the most commonly cited problems at course level, as identified by 60% of those consulted (Sunal et al., 2000). Carl Weiman and his colleagues (Weiman et al., 2010) assert that *"more effective teaching need not take additional time or money, although the process of change requires additional resources"*. The costs associated with change are estimated by the authors to be around 5% of the departmental annual budget, over a period of five years.

- **External networks.** The literature stresses the importance of faculty teaching and learning networks (Fairweather, 2008) and external disciplinary societies (Kezar, 2009) in encouraging dialogue, exchange of educational ideas and engagement with reform efforts. In particular, communication across networks appears to be most effective when the membership is confined to discipline-specific faculty (Borrego et al., 2010).

- ***Culture and rewards procedures.*** Considerable attention is given in the engineering education literature to the issues of *organisational culture* and *rewards procedures*, and the role they play in supporting, or hindering, change. Due to the volume of information in this field, a summary of the literature is presented in a separate section (Section 2.6).

- ***Sustaining the change.*** The issue of sustainability of educational change is rarely touched upon in the engineering educational literature. When considering the management of change to PBL in engineering, de Graaf and Kolmos (2007) refer to the work on sustaining change at primary and secondary school level from Fullan (2005). This work advocates the creation of "*recurrent energizers to pass from a phase of change to continuous improvement*". In addition to these 'energisers', the broader literature on educational change across all STEM disciplines (Kezar, 2009) points to the need for on-going funding and operational support, if changes are to be insitutionalised and sustained – "*Many changes have come and gone because they never had enough structural support, so they were the first to be removed in times of fiscal scarcity… For changes to be sustainable, they need to become part of the institutional structure, budgeting and priorities*". Evidence on sustaining change from the literature spanning all higher education disciplines points to the importance of the innovation being 'home grown' (Trowler et al., 2003) and the need for reforms to "*become valued – and practiced – by a larger group than the original innovators*" (Colbeck, 2002).

2.6 Culture and rewards procedures

Within the literature on engineering education reform, the issues of *organisational culture* and *academic rewards procedures* are topics of considerable discussion (Godfrey and Parker, 2010, Merton et al., 2004, Bjorklund and Colbeck, 2001, Fairweather, 2008, Institution of Engineers, Australia, 1996). Indeed, a recent US forum on educational change in engineering identified university reward systems as "*the main structural deterrent to faculty who are otherwise disposed to revise their teaching*" (Seymour et al., 2011). However, although "*changing the culture*" is a phrase used in many recent reports on engineering education, the prevailing culture is rarely defined and suggested strategies for cultural change are limited. One exception is the work by Godfrey and Parker (2010), who analyse in some detail the organisational culture within the School of Engineering at the University of Auckland.

For many, "…*without changing incentives or making appeals to intrinsic motivators, faculty members inevitably focus on the activities visibly rewarded by their institutions and peers*" (Fisher et al., 2003). Indeed, some see academic cultures in engineering becoming more research-driven with time, as new generations of faculty have been "*hired and promoted at many of our research intensive institutions primarily because of their strengths in research and 'grantsmanship'*" (Splitt, 2002). This observation is supported by the findings of a study of US STEM faculty, which demonstrated that average faculty teaching hours correlates negatively with salary levels (Fairweather, 2005).

Merton et al. (2004) highlight the impact of organisational culture, by contrasting two reform efforts in engineering education at Rose-Hulman Institute of Technology. They argue that the success of one effort, and failure of the other, was due to the extent to which the reforms were adapted to the organisation culture. This finding, that alignment to the institution's culture is essential if a programme of educational reform is to be successful, is supported by evidence on educational change across higher education (Kezar and Eckle, 2002). Fisher et al. (2003) argue that the development of a culture of *collective responsibility* among faculty is a critical element of systemic and sustainable reform. They argue that the autonomous nature of the academic role creates a tension between the "*perspective of a curriculum as a unified whole that is intended to shape the characteristics of its graduates and the perspective of the curriculum as a collection of individual courses for which individual faculty members accept responsibility*".

Research evidence from the US suggests that the perceived priority given to teaching in engineering rewards procedures has changed little, or even, for some, declined, in recent years (Lattuca, 2011). The study also suggested that more senior staff were more likely than faculty to perceive a greater value being placed on teaching during promotions procedures. This outcome is mirrored in the findings of a recent UK study, looking at the reward and recognition for teaching and learning (Cashmore and Ramsden, 2009).

2.7 Measuring the impact of change

The review revealed limited evidence on the impact of reform efforts in engineering education and what exists to be of largely poor quality. This observation is echoed by findings from an analysis of the literature on educational change across STEM disciplines (Henderson et al., 2011). This study concluded that "*although most articles claim success of the change strategy studied, the evidence presented to support these claims is typically not strong*". At a recent gathering of US-based experts in educational change in engineering, one theme emerging was the lack of rigorous measures to evaluate the impact of reform efforts (Seymour et al., 2011).

The weakness of evidence in this area may be also a symptom of a wider problem in measuring and evaluating good teaching practice. Three programmes of reforms appear to have used a rigorous approach to evaluation and were recommended during the interview process for this study: Gallos et al. (2005), Gillan-Daniel (2008) and Stelzer et al. (2009). A summary of alternative approaches to evaluating the quality of an engineering education programme is provided by Molyneaux et al. (2010), as part of their efforts to evaluate the impact of educational reforms in the School of Civil, Environmental and Chemical Engineering at RMIT in Australia.

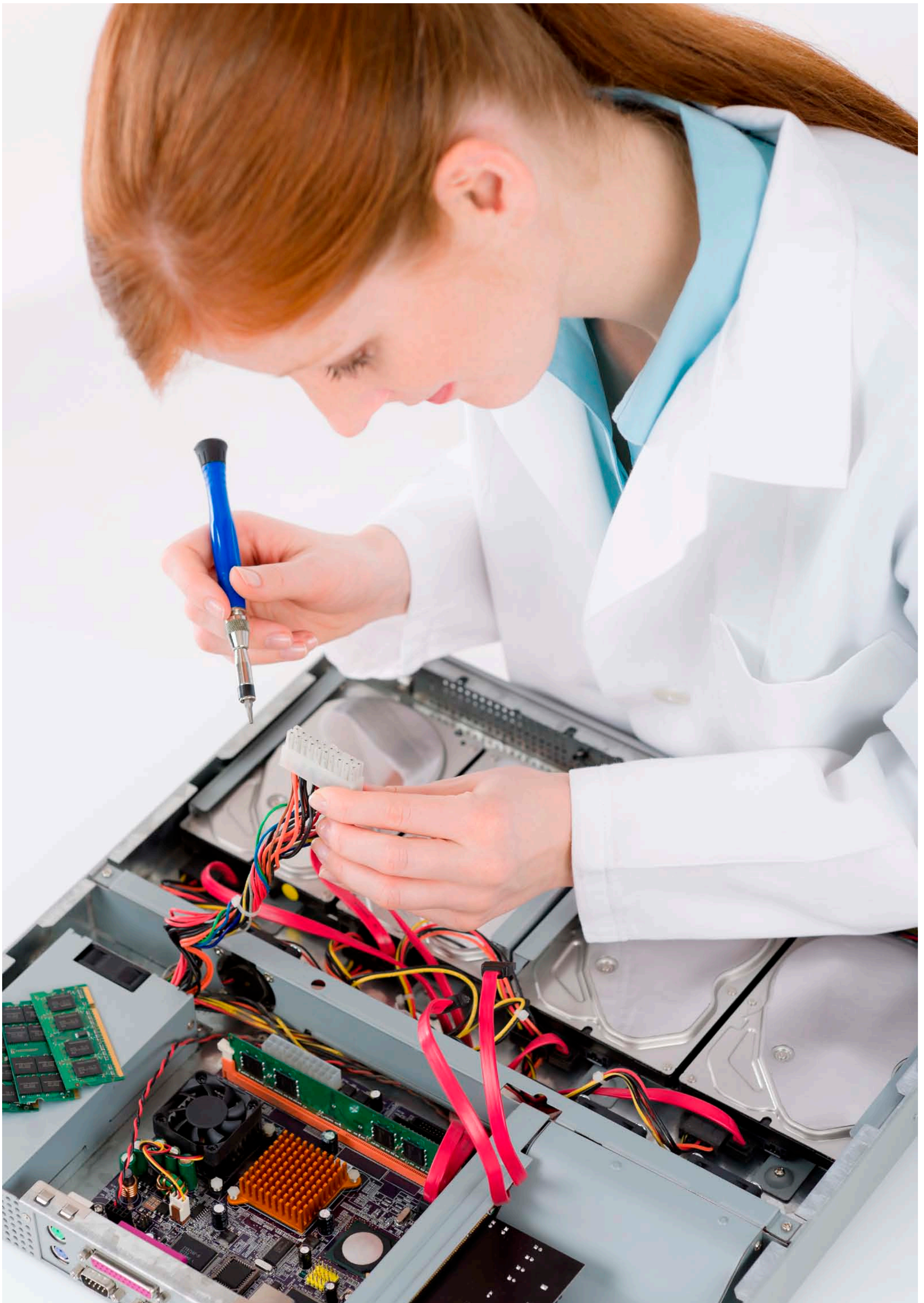
2.8 Is further evidence on change in engineering education needed?

This chapter has highlighted a dearth of information of how to achieve successful, widespread change to the engineering curriculum. One final task of the literature review was to establish whether, indeed, a study looking at educational change in the specific discipline of *engineering* was necessary, or whether the change strategies proven to be successful in other higher education disciplines should hold equally well for engineering departments. The evidence suggests that, although many lessons can be learnt from looking at educational change across higher education, there was considerable merit in considering change within *engineering* specifically:

- ***Perceived relevance of the study outcomes:*** The first issue is simply one of maximising the credibility and acceptability of the study outcomes among the target audience – within any academic discipline community, the outcomes of research in undergraduate education are most effective when they are grounded within that discipline (Cousin et al., 2003, Borrego et al., 2010). As Huber and Morreale (2002) noted "*For good or ill, scholars of teaching and learning must address field-specific issues if they are going to be heard in their own disciplines, and they must speak in language that their colleagues understand*".

- ***Differences in attitudes, approaches and expectations in engineering Schools/departments.*** The second issue relates to inherent disciplinary differences that shape the context for educational change – significant differences are apparent in both attitudes and approaches to teaching and learning among both engineering students and faculty, as compared to those in other disciplines (Lattucca and Stark, 1994, Litzinger et al., 2011). Indeed, some evidence even points to differences existing *between* engineering disciplines in both awareness and adoption of educational innovations (Borrego et al., 2010) and limited cross-fertilisation of effective practice between discipline boundaries (Wankat, 2011). A recent study on educational excellence in research-led institutions concluded that "*academic discipline was found to have a profound affect on the form of leadership of teaching and the form of educational change associated with excellence in teaching... Any advice about leadership of teaching should take into account these disciplinary characteristics and cultures or it is likely to risk being not just irrelevant but wrong*" (Gibbs et al., 2009).

Against this background, a study was undertaken to evaluate the key features of successful and unsuccessful change strategies in engineering education. The findings of this study are reported in the chapters that follow.



3 Evidence from interviews with educational change experts and past reform leaders

This chapter distils the insights of international experts and practitioners in engineering education into the process of educational change. One-to-one interviews were undertaken between January and October 2011. Drawing on their knowledge and experience, the chapter describes the conditions and mechanisms for achieving successful and sustainable change in engineering undergraduate education.

Section 3.1 describes the interview approach. Subsequent sections (3.2 to 3.6) then describe what they revealed. Section 3.2 synthesises views on the current prospects for educational change in engineering from countries across the world. The most highly-regarded examples of educational change in engineering are summarised in Section 3.3, as identified by interviewees. Section 3.4 discusses the circumstances under which widespread changes are typically triggered. Strategies commonly employed for managing change are presented in Section 3.5, along with the approaches often associated with success and failure. Finally, Section 3.6 presents interviewee feedback on how curriculum changes are both evaluated and sustained.

3.1 The interview study

One-to-one interviews were held with 70 individuals from 15 countries. The broad geographic mix of interviewees is illustrated in Figure 2. A list of those consulted for this section of study is provided in Appendix B. A small number of these individuals (11 in total) also contributed to the case study investigations (as presented in Chapter 4 of this report).

A snowballing method was used to identify potential interviewees. An initial list of 15 individuals was compiled, drawing in equal numbers from the following four groups: (i) those with a national view on engineering education practice (policy-makers, leaders of national engineering education organisations, accreditation agencies etc.), (ii) researchers in educational change within engineering or STEM disciplines, (iii) those who have observed educational changes, such as faculty from peer competitor universities or industry employers and (iv) those who have led programmes of educational change within engineering Schools or departments. Further interviewees were identified by recommendation, with a predominant focus on those who have led educational reforms, both successful and unsuccessful. Figure 3 illustrates the overall mix of those interviewed for this phase of the study, presenting, in each case, the primary reason for their selection. In total, 89 individuals were invited to participate in the study interviews, with 19 of those unwilling or unable to contribute.

Interview questions were designed to evaluate the *process* of educational change in engineering rather than the goals, pedagogy or curricular design of a reform effort. They focused principally on: (i) the circumstances under which a systemic reform is triggered, (ii) the potential barriers to change and the critical success factors, (iii) impact evaluation, and (iv) why and how change is sustained. Given that roughly 60% of the interviewees had themselves led an educational reform

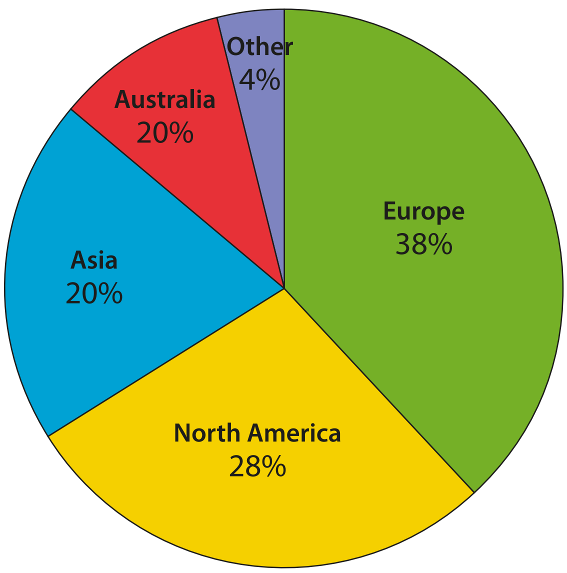


Figure 2. Continent of residence of interviewees

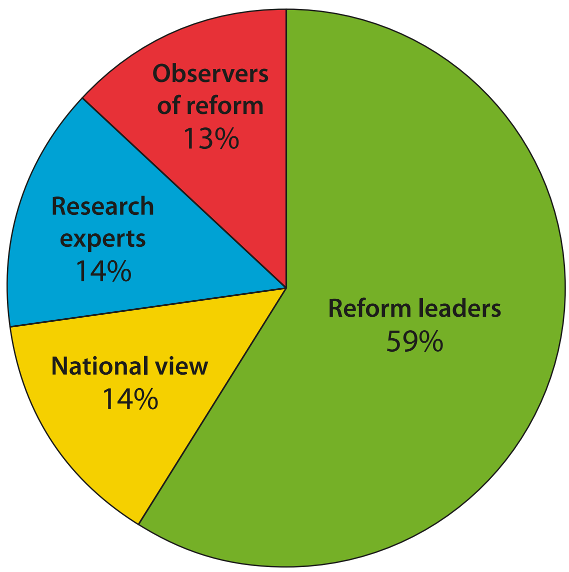


Figure 3. Primary reason for selection of individual for interview

effort, they were disproportionately more likely to believe that some fundamental change was necessary to current educational practice. In this respect, the attitudes of this group are unlikely to be representative of engineering faculty as a whole.

During this chapter, reference is made to 'successful' and 'effective' change. For the purposes of this chapter of the study, the success or otherwise of reform efforts were self-reported by those leading, participating in or observing the change. No independent evaluations were conducted to validate their efficacy.

3.2 Prospects for change across the world

Interviewees were asked to comment on the current climate for educational change within their countries of residence. The responses to this question varied considerably, with some expressing great uncertainty about the potential for curriculum reform over the coming decade and others talking much more optimistically about shifting attitudes and increasing resources for change.

At a very broad level, a number of interviewees talked about national cultural differences that continue to play a significant role in the capability of an engineering School or department to make an educational change. For example, some felt that, "*change is difficult in countries where the professor has the power, such as Germany, and particularly the US*". In contrast, countries where the management or administration have greater control over the curriculum and the direct link between faculty member and course is less apparent, such as Denmark or Australia, are seen to have much greater potential for change.

The majority of the feedback, however, centred on recent shifts in the climate for undertaking an educational change, and focused on three factors seen as critical to initiating and facilitating curriculum reform: (i) the support available at a national level, (ii) the resource available at an institutional (departmental or School) level, and (iii) the balance between teaching and research. Each is discussed below.

National support: The first factor concerned the changing national climate for supporting educational change in engineering. Many interviewees spoke about a growing national engagement with engineering education over the past decade, often catalysed by flagship national reports and communities of support – "*the past 10 years has been fantastic. With these new networks, a critical mass has developed to talk about and push forward new [educational] innovations*". However, in more recent years, the funding streams supporting such centralised activities have been severely cut in a number of countries. The picture across different countries is highly variable. While some countries, such as South Korea or Germany, point to the establishment of new national support centres in engineering education, others see such centres being dismantled or down-sized. For example, the UK-based support centre for undergraduate engineering education was closed in July 2011. The Engineering Subject Centre was seen as a key catalyst in developing a UK community of support in engineering education, and there is great concern over the impact of its closure – "*the Subject Centre legitimises what many people are trying to do in education in their own institutions. Without it, they may feel that they do not have any visibility and no opportunities to network. There is a very strong level of uncertainty about what will happen with this closure*". International engineering education communities, such as the CDIO[2] network, appear to play a particularly strong role in supporting change in those countries where no national centre exists. Many interviewees, however, found attending networking events and conferences in engineering education very challenging, as there were no national funding streams available and departments were often unwilling or unable to resource such activities.

Institutional resourcing: The second critical factor concerned the extent of resource availability for change at departmental or School level, and how this has changed in recent years. Again, considerable variation exists between countries in this area. In particular, it is interesting to note that many of those countries who have been particularly active in the international dialogue on education reform in engineering over the past 20 years (such as the US, UK and Australia) appear to be currently experiencing a period of considerable retrenchment and resource constraint, linked to government-led restructuring or funding changes. Some interviewees from these regions pointed to a highly pressurised educational system that, currently, does not have the capacity for change. For example, as one US-based interviewee commented, "*so many people are just overwhelmed by the budget cuts at the moment. We can't even get people to staff the classes, so we are not even going to start to do something creative*". Indeed, for some, university-wide financial pressures were impacting on all engineering education activities outside the core curriculum. As noted by one UK-based interviewee, "*every bit of expenditure is back on the table for scrutiny, including engineering education projects that had been previously given the go-ahead*". In contrast, many of those countries that have become engaged in the international engineering education dialogue in more recent years (such as perhaps Hong Kong, Singapore or Malaysia) reported increasing resource availability for educational innovation and change.

Research/teaching balance: The final issue concerned the perceived balance between research and teaching within engineering School/departments. A recurrent theme in the interviews was the perception of a shift in priorities towards research and away from teaching over the past 5 years. The sentiments of this interviewee were typical of many – "*going back 15 years, and comparing that with the situation 5 years ago, education had become more important. I can see now, though, there is more tendency for the priority to move back to research and focus on paper publication*". This increasing emphasis did not appear to be confined to any particular country or university type. A number of interviewees spoke about these changes being driven by the increasing influence of university ranking systems. Many pointed to specific national-level triggers, including recent changes to the system of national university research rankings (such as the introduction of

2 CDIO (Conceive, Design, Implement, Operate) initiative (www.cdio.org)

Excellence in Research Australia in Australia) or a change in priorities of national research funding bodies (such as that recently implemented by the *Natural Sciences and Engineering Research Council* in Canada). As one interviewee noted, "*over the last three or four years, the pressure for research output has increased a lot. We have a real obsession with rankings, and they only want to measure the research*". For some interviewees, these changes "*are creating a culture of fear amongst faculty. They are worried about getting their research funding and they are becoming concerned about the time they spend on teaching*". An additional consequence of this increased pressure on research output appears to have been a reduction in the number of faculty with "*real industry experience*". For a number of interviewees, such faculty members tend to be less tied to "*the way we do things around here*" and bring a stronger drive to incorporate authentic engineering experiences into the curriculum. Indeed, the successful change efforts described by interviewees disproportionately involved faculty with significant levels of industry experience.

A surprising number of interviewees also spoke with concern about the impact of a changing research/teaching balance on younger faculty. Despite what was described as a "*natural tendency to be more interested in creative ways of teaching*", the culture into which younger faculty have been appointed and the increasing pressures on them to meet ambitious research targets is seen to have significantly reduced their engagement with engineering education generally and educational reform specifically. The observation of this interviewee was typical of many – "*those of us who are established now in engineering education will probably stick with it. We have accepted that our career progression will be retarded but we will continue. The threat is really to the early career academics, who are just getting into their career. The demands now being put on the research domain are intense. The risk is that when we retire, there will be a lack of succession … The dollar hitting the university will be the real thing that sets the agenda. Unfortunately, the funding change is in the wrong direction for engineering education at the moment*".

3.3 Examples of highly-regarded change

All interviewees were asked to identify national and international examples of planned, significant change in engineering education, which, from their perspective, have been effective. Figure 4 records all of those reform efforts that were identified by 5 or more interviewees. It should also be noted that most interviewees identified examples predominantly from within their country of residence, which has skewed the results towards to UK and US. It is interesting to note that the majority of reform programmes listed in Figure 4 centre on the implementation of problem-based or project-based learning approach within an authentic, professional engineering context.

A small number of interviewees did not feel qualified/able to identify examples of 'successful' change and talked about the difficulty in judging the quality of a reform effort as an external observer. In particular, some commented that there was often a lack of honesty about the true scale and nature of reform efforts, where, on further inspection, impressive claims of radical, widespread reform "*turn out to be little more than smoke and mirrors*". The narratives presented at engineering education conferences was seen, by some, to be in stark contrast to the real changes happening on the ground in the host institution. As one interviewee commented "*Making change is dirty work and it adversely affects your career. It is so much easier to travel around the world and talk about the fantasy version of your changes, … than it is to stay at home and deal with the realities of actually making it happen*".

National and international engineering education communities clearly play an important role in supporting many change efforts. Probably the most successful example is the CDIO[2] initiative, which appears to have been effective in raising awareness of new approaches to engineering education, but also in triggering systemic and effective change at many of the participating universities. In addition to the "*well thought-through educational structure*" and international community of support, the success of CDIO was credited by some to the endorsement and leadership of the initiative by MIT. As one of the interviewees commented "*…[the involvement of MIT] has brought a lot more people in and reassured people that this is not about 'dumbing down'... I am not sure whether [CDIO] would have been as effective without MIT at the front*". Other interviewees also discussed similar "*lead institution effects*", where the involvement of a highly-regarded, research-led, institution in a educational change effort would trigger the involvement of international partners.

3.4 The conditions that trigger change

3.4.1 Drivers for embarking on change

Interviewees were asked to identify the key drivers for educational change in engineering. The factors that they identified as driving change at course level were in sharp contrast to those triggering systemic or curriculum-wide change, as discussed below.

When implemented by an individual faculty member or small groups of individuals, change was seen to be triggered by persuasive evidence of the efficacy of new pedagogies and/or broader national/international drivers such as the changing needs of industry or the role of engineering in solving the 'grand challenges'. The evidence from the interviews indicated that such educational changes are usually implemented at the periphery of the curriculum, typically within a single curricular course, an extra-curricular programme or an optional/specialist class. These changes appear unlikely both to be sustained beyond the tenure of the champion/s or promulgated more widely within the curriculum – "*you usually have one or two enthusiasts in a department who do something [innovative]. When they leave, everyone breathes a sigh of relief and reverts to the status quo*".

In contrast, the national-level needs and/or pedagogical evidence do not appear to play a major role in triggering successful School/department-wide change or strategic reforms across a significant proportion of the curriculum. This point was particularly evident in the interviews with leaders of systemic reform effects viewed to be both successfully implemented and effectively sustained. The vast majority described the triggers for change either in

Aalborg University (all engineering programmes), Denmark
Chalmers (all engineering programmes), Sweden
Coventry University (Faculty of Engineering and Computing), UK
Georgia Tech (International Plan), US
Harvey Mudd (Engineering Clinic), US
Olin College (all engineering programmes), US
Penn State (Learning Factory), US
Purdue University (both GEARE and EPICS), US
RMIT (School of Civil Environmental and Chemical Engineering), Australia
Singapore Polytechnic (all engineering programmes), Singapore
Technical University of Denmark (first year engineering programme), Denmark
The Hong Kong University of Science and Technology (School of Engineering), Hong Kong
TU Delft (Faculties of Industrial Design Engineering and Aerospace Engineering), Netherlands
UCL (Department of Civil, Environmental & Geomatic Engineering), UK
University of Colorado at Boulder (Integrated Teaching and Learning Laboratory), US
University of Illinois (iFoundry), US
University of Liverpool (School of Engineering), UK
University of Queensland (Chemical Engineering), Australia
University of Sydney (all engineering programmes), Australia
University of Technology Malaysia (all engineering programmes), Malaysia

Figure 4. Programmes of educational change in engineering, endorsed by 5 or more interviewees

terms of a very significant threat that required urgent action or an externally-imposed requirement for fundamental structural change. Specifically, most changes are driven by a critical problem with their "*position in the market-place*", often declining student intake quality/quantity, increasingly fierce competition or very poor student satisfaction scores, resulting in significant pressure to change from the university senior management. In a surprising number of these cases, departments were given the option of either reforming their education or being closed down. These pressures were seen to focus the minds of the faculty – "*we had a gun to our heads…This was still there even after we made the changes. The looming storm was always on our minds*". Amongst successful reform efforts, this enforced need for fundamental change also appears to engage faculty in the collective challenge of the endeavour. This reaction was described by interviewees in many different terms, from "*enjoying the fight*", to "*engaging faculty's intrinsic motivation for change*" to simply the sense that "*if we were going to have to do something, it may as well be good*".

Although exceptions clearly exist, as a general rule, unsuccessful or unsustained systemic changes appear much more likely to be driven by factors that were not seen as urgent or externally imposed – typically a desire to "*improve an already relatively successful*" undergraduate education and/or in response to pedagogical evidence on the efficacy of a particular pedagogy. There appear, however, to be two circumstances under which this general observation does not hold true:

1. change within departments/Schools where a strong collegial, entrepreneurial culture of educational risk-taking and innovation already exists. In such cases, the existing feeling of collective responsibility for the undergraduate programme creates widespread engagement with the educational goals and minimises resistance. Faculty also hold a strong belief that their efforts in improving the curriculum will be both recognised and rewarded. The outcomes of the interview phase of this study suggest that around 5–10% of successful programmes of change could be placed in this category. One example of such a change is the Department of Chemical Engineering at the University of Queensland, detailed as a case study in Chapter 4.

2. change that has benefitted from very significant injection of funding sourced from outside of the

university. In these cases, almost exclusively US-based, the external resources will typically bring significant prestige, beneficial long-term partnerships and often new educational facilities and learning spaces. More importantly, however, the funding will buy out most, if not all, of the faculty time required to make the change. The resulting reform, therefore, rarely calls for the engagement of any unwilling faculty and is an activity that does not need to compete with existing resources. As such, these changes encounter very little faculty resistance in their implementation. Around 5–10% of the programmes of change investigated could be placed in this category. One example from this study is the Learning Factory from Penn State (see case study from Chapter 4).

3.4.2 Barriers to embarking on change

Interviewees were asked what they saw as the key barriers to embarking on systemic educational change. A summary of those barriers most commonly identified is provided below.

- ***Widespread satisfaction with the status quo:*** This issue appears to be the most prevalent barrier to change, particularly within research-led institutions. For many, "*if staff are happy and you are getting good students, why change?*".

- ***Difficulties in measuring success:*** The issue that "*no-one knows how to measure good teaching on a wide scale*" has been a major deterrent to some. As one interviewee commented, "*when people don't really know what impact their teaching is having [now], how can they contemplate doing things differently?… The risks associated with change appears to be greater than the risks associated with doing nothing*".

- ***'Overstuffed' curriculum:*** Given that many changes, historically, have resulted in an increased number of student contact hours, many feel that their curriculum is now operating at its maximum capacity and further change is not an option –"*there is vey little space in the curriculum. Unless you overhaul it completely, there is little room to manoeuvre*".

- ***Structural constraints:*** Although sympathetic to the need for change, some faculty would point to institutional structural constraints as significant barriers. These would include insufficient departmental budgets, inadequate teaching spaces and/or a rigid curriculum structure that (for example) could not support immersive project experiences.

- ***Legacy of failure***: A surprising number of interviewees talked about the long-term impact of failed reforms and how their legacy can "*stifle any attempts at change to the curriculum, beyond individual courses, for a decade or more*". Unsuccessful reforms (or those viewed to be unsuccessful) appear to hold an influence beyond their own department or institution. For example, a number of UK-based interviewees referred to one particular reform effort to implement problem-based learning within the engineering curriculum at a major UK research-led university. Each noted how the widespread perception of the failure of this ambitious change was leveraged by many faculty as a reason not to engage in educational change – "*the plans were quite radical. The rest of us were watching and waiting to see whether they were able to pull it off. As so many of the changes did not survive … it is now used as proof by many of the resistant academics that these sorts of teaching approaches will not be supported and are not sustainable*".

- ***Strategic priorities of the institution:*** The priority given to research activities at many universities was seen to be a significant disincentive for departments to become involved with educational change. This issue is discussed in more detail in Section 3.4.4.

3.4.3 Impact of engineering accreditation or national evaluations

Interviewees working within an engineering School or department were asked about the extent to which their accreditation system (or national equivalent) supported positive curricular change. The responses varied considerably. Indeed, even the views held by interviewees within some countries (most notably the UK) were highly polarised on this issue. For those who felt able to comment, the responses broadly fell into three groups, as outlined below.

1. ***Accreditation as a deterrent for positive change:*** Almost a quarter of respondents believed that accreditation had fostered a risk-adverse attitude amongst faculty, where "*maintaining the status-quo is the safest option*". The individuals expressing this view were almost exclusively experienced reform leaders, based in countries that have been engaged in the international engineering education debate for many decades (principally the UK, US and Scandinavia). Some reported that the fear of non-compliance with accreditation criteria deters many faculty from investing significant time in educational change or in implementing new educational approaches – "*although the problem may be reducing, many academics will err on the side of caution, and do not wish to take the risk that any proposed change would jeopardise the department's accreditation status*". Such concerns, when expressed within departmental curriculum planning meetings, were reported to "*block*" any proposed curricular changes. Most interviewees, however, still noted that it would be very unusual for any programme, however radical, not be granted accreditation. The fault, for many, is with the visiting accreditation panels, and the impression they leave on faculty, rather than with the standards themselves.

2. ***Accreditation as a driver for slow positive change:*** Almost two thirds of respondents felt that accreditation has had a positive, albeit slow, impact on educational quality. In particular, the widespread move to outcomes-based accreditation is seen to have raised the baseline quality of engineering education across the sector. They viewed these new accreditation frameworks as holding departments to account for what they are delivering – "*there was a lot more space to hide poor teaching in the*

old system, as well as make unsubstantiated claims about what you were doing". The reported positive impacts of the introduction of outcomes-based accreditation included: (i) a broader engagement amongst faculty with *"what the students need to learn, rather than what do we want to teach"*, and (ii) an increased engagement by faculty with the broader aims of the degree programme and curriculum structure as a whole.

3. ***Accreditation as a driver for significant positive change:*** A smaller number (around 10%) of respondents believed that either the act of seeking accreditation with a new agency or the shift of their existing accreditation framework to an outcomes based system had triggered a significant improvement in national engineering education practice. For example, in Chile, fierce competition for students has resulted in a number of engineering programmes seeking international accreditation status, principally through ABET, in addition to the national standards, in order to "*improve their credibility, status and international ranking*". Within a number of Chilean engineering Schools and departments, achieving accreditation with multiple agencies has resulted in a fundamental reassessment of their educational approach and positive reform of the curriculum.

3.4.4 Impact of academic rewards procedures

A recurrent theme in the interviews was the importance of the "*prevailing culture in engineering departments*" and, in particular, the emphasis placed on research in the appointment and promotion process. There was a consensus that the priority given to research acted as a major deterrent to faculty engaging with or supporting any programme of educational change. Opinion, however, was divided on its implications for supporting change across the sector, as summarised below.

- Some interviewees believed that positive, systemic and sustainable change to engineering education would not be possible without a fundamental re-alignment of the academic rewards procedures. They argued that the present system disproportionately rewards quality and impact of research output at an individual faculty level, and provides little incentive to devote significant effort to education, let alone educational change. As one interviewee noted, "*at the moment we are relying on those people who just want to do it, for us [engineering departments] to make any changes at all. But these people will never get promoted. They are like lepers. No one wants to catch what they have*".

- Other interviewees, however, believed that change to the rewards structure was not a realistic option, and the energy currently devoted to this "*futile exercise*" has been at the expense of activities that were more likely to improve educational practice. As one interviewee commented, "*I think [talking about the need to change the rewards system] gets people off the hook too easily – it's so easy to complain about it, but then it stops people from doing anything*". For some, the key to change was to build the intrinsic motivation of faculty – "*in most departments, you can get out of teaching by doing a really bad job. Rather than worrying about the rewards system, [we should] make teaching an enjoyable experience, and people will be motivated to do a good job*".

Most respondents were agreed, however, that creating a culture that supports educational change "*all boils down to people*" and whether faculty believe that senior management will consider educational contributions "*when they are sitting in a room, deciding who gets promoted*".

3.4.5 The context for reform efforts

It was clear from the interviews that there were common features in the institutional contexts of successful reform programmes. In almost every case, at least two of the factors below were present; in some, all factors were noted.

- ***Faculty experience:*** an unusually high proportion of faculty have industry experience or a non-traditional academic background;

- ***Effective departmental leadership:*** a well-regarded, internally-appointed Head of Department with a very strong internal reputation for educational commitment and delivery and a strong national/international reputation for their research activities. The individual has typically been in post for a number of years before the change is initiated;

- ***Externally-imposed re-structuring:*** an upcoming sector-wide educational restructuring – typically national changes across the higher education sector, a move to an outcomes-based accreditation system or a move to Bologna compliance;

- ***Recent staff changes:*** the recent appointment of a significant number of new, and often younger, faculty members and/or significant changes to senior university management;

- ***Personal experience of failure:*** the involvement of some of the change leaders in a prior 'failed' course-level reform, typically at a different institution, from which they concluded that "*change needed to be radical and widespread for it to stick*";

- ***New infrastructure:*** the recent award for funding of a new building or significant number of new learning spaces. As one interviewee commented, "*if the university is already investing money in infrastructure, it is more likely to support a parallel change to the curriculum*".

Many interviewees described the coming together of a number of these factors in terms of "*a degree of serendipity*" and "*being in the right place at the right time*". In this context, some reform leaders saw their greatest contribution to the reform effort as "*watching a number of events come together and knowing when to make the move*".

It is also interesting to note that prior engagement with curriculum-wide educational innovations and/or pedagogical evidence does not appear to be more prevalent in the successful examples of change than in those deemed to have been unsuccessful. In a small number of cases, pedagogical evidence played an important role in awareness-raising, but was rarely the trigger to embark on change at a systemic level. As one interviewee commented – "*The data [pedagogical evidence] get's people's attention, it does not translate into action. A lot of things will raise awareness, but they do not do anything until someone's house is on fire*". A number of interviewees, particularly those from research-led institutions, spoke with some frustration about how ineffective they have found pedagogical evidence to be in triggering change – "*I presented good data on the efficacy of an approach in terms of learning. [Faculty] accepted that. That is not the issue. Some yahoo will always get up and say "I tried it and it didn't work". Anecdotal experience of one faculty tends to trump evidence every time, even though the research methodology is accepted*".

3.5 Managing the change process

The previous section (3.4) discussed the conditions and drivers often present before a department/School embarks on a programme of educational reform. This section discusses the strategies actively employed by departments/School in managing the process of change itself.

3.5.1 The agents of change

Interviewees were asked to identify *who* they saw as the critical players in achieving a successful and sustainable educational change.

There was a broad consensus that successful, systemic educational change was usually the product of a "*balance of top-down and bottom-up pressure*". Indeed, for some, achieving this balance was the key to successful change – "*a Head of Department or Dean with a mandate and a strong vision who give the faculty time and space to do something with it that they can own. This is the real trick to pull* off". Within this broad picture, interviewees also spoke about the role played by particular groups or individuals in the change process. These observations are summarised below.

Senior School and university management: Almost all of the successful, systemic change programmes described by interviewees had the explicit support of the Dean or key members of university senior management. Many interviewees talked about the critical importance of this support in galvanising faculty engagement. In particular, faculty must "*trust the system*" and feel confident that their efforts will be recognised (if not explicitly rewarded) by the institution during promotions procedures. One interviewee spoke about a widespread curriculum change in engineering that was "*completely de-railed and, ultimately, abandoned*" when the university Rector delivered a public address underlining the centrality of research to the strategic mission of the institution.

Head of Department: One particularly striking outcome of the study was the extent to which the Head of Department was identified as central to change. Regardless of the scale of reform, the enthusiastic support of a credible and well-respected Head of Department appeared to be the single greatest predictor of its success and sustainability. As one interviewee commented "*Having a supportive Dean is important, but the Head of Department in critical… Ultimately, the Head of Department has the power on the resources and the culture*". On the same theme, another noted "*There is a close tie between the department head and hiring… If they communicate to the new hires that teaching is important, there will be a big impact. It is very important for whatever direction you take*".

Change leaders: In most cases of successful change, the leader or co-leader was the Head of Department. In many cases, the endeavour was led by two key individuals, one, typically the Department Head, providing the direction and energy, and the other producing a "*coherent backbone to the changes*" and mapping the vision into a logical curriculum structure. Many leaders of successful changes also reflected on their own roles during the early stages of the change – *"You need to have people who are a little crazy and willing to invest their life in something that is totally different*" and "*We really had no idea what we were taking on. Without that naivety we would probably never have done it, though*".

Faculty: When interviewees were asked for their advice for others embarking on reform, it was engaging faculty that was most frequently noted ("*bring them with you*"). When discussing engagement strategies, many pointed to three distinct faculty groupings, each of roughly equal size:

- group 1 – faculty who do not support the proposed change and are actively resistant to any shift away from the existing curriculum;
- group 2 – faculty who are highly focused on other activities, principally their research, and "*do not care either way*" whether the changes are implemented;
- group 3 – faculty who support the change.

Many interviewees advised that group 1 are unlikely to ever be supportive of educational reform, and any attempts to force or coerce them into changing their educational practice would be counter-productive. The advice was therefore to "*work around them*" and allow "*these people to carry on with their existing teaching as they were before [and] do not force them to become involved*". Indeed, many successful changes have left one 'ring-fenced' section of the curriculum, where the content and delivery remains largely unchanged in which this group of faculty can operate.

Much of the advice therefore focused on faculty within groups 2 and 3, and "*put[ting] your energies into supporting the third that support change and into converting the third that don't care*". In particular, the advice for engaging group 2 centred on highlighting the underlying drivers for change and the benefits that reform will bring – "*these people tend to be committed to the students, but are busy and focused on their research. They need to be convinced that there is a real need for such a significant disruption*". Within large departments, with fragmented and siloed research groups, reaching such faculty is often very challenging. The results of benchmarking exercises with world-leading research universities were seen to be of particular interest to this group, particularly where the messages were delivered by those with "*intellectual authority* *within their [engineering] discipline"*. Many felt that this group would not be convinced by pedagogical evidence, particularly where it is presented by non-engineers. In contrast, evidence of pedagogical efficacy was seen to resonate strongly with those within group 3 and provide them with both the confidence and tools to improve student learning.

Students: A number of highly-experienced reform leaders spoke with some disappointment about the minimal influence students have had on the progress of curriculum change to date. As one commented "*it was a fantasy of mine for years and years – if I created courses that students really responded to, they would go off from this experience and advocate for that in other courses. This just did not happen*". Another observed "*I used to feel that students would vote with their feet, but they only tend to make small deviations. At the end of the day, employers will recruit from the top ranked universities, and students will continue to [seek employment from them] – the student is not the end consumer, the employer is, so students are very adverse to changing the formula*". These observations appear to be well founded. No instances were identified in this study where positive student engagement was a primary driver for curriculum change. The student voice only appears to play a prominent role in progressing change where levels of dissatisfaction impact on the reputation and/or operation of the undergraduate programmes. It should be noted, however, that student input is often used, to great effect, to inform the *educational design and approach* of curricular changes. However, the likelihood and ease with which these changes are implemented, on the other hand, does not appear to be improved by positive student engagement.

3.5.2 Common strategies in successful change

Interviewees who had been involved with or observed programmes of educational change were asked to describe the strategies adopted. Two particularly strong themes were apparent in the successful change programmes described, focusing on activities which built: (i) faculty engagement in the underlying need for the change, and (ii) a collegiality across the faculty and a sense of collective responsibility for the curriculum as a whole. In addition, a number of common stages were apparent across many of the successful change strategies. These are outlined below, sub-divided into three phases of activity: *preparation*, *planning* and *implementation*. As can be seen, the two themes of *engaging faculty in the need for change* and *creating a collective responsibility for the undergraduate programmes* are woven into many of the stages described.

Phase 1: Preparatory work

Local evidence gathering: Building a strong evidence base for the need for change has been a highly effective strategy for engaging faculty and university management in the reform process. Such evidence appears to have the greatest impact when focused in the following areas: (i) data quantifying the critical drivers for change, such as student intake numbers or retention rates, as compared to peer competitor institutions, and (ii) feedback from engineering graduate employers on employability, comparing their own graduates to that of competitor institutions.

Benchmarking of educational approach: Most successful change programmes conducted a brief benchmarking process to inform their curriculum design process. As a general rule, it appears that benchmarking both against a premier research-led institution, principally Stanford or MIT ("…*if these universities are doing similar things – faculty think that you are on the right track*") and peer, competitor, universities tends to engage faculty most positively with the change process. It is interesting to note that faculty resistance sometimes appears to increase if change leaders point to highly innovative institutions, such as Olin College in the US and Aalborg University in Denmark, when proposing educational reforms – "…*they have such different students and so much more money available, and a completely different structure… Telling [faculty] that we are going to try to do something similar is really not going down well*".

Presenting the early vision to senior management: In a number of cases, the broad vision for change was presented to university senior management before discussions were held with faculty. Although somewhat of a risk, these early consultations can provide some significant advantages. In particular, they can allow: (i) reform decisions to be made on the basis of known institutional constraints, (ii) where structural conflicts exists, the exploration of options for moulding or changing existing university regulations to accommodate the proposed changes, and (ii) reform leaders to demonstrate to faculty "*from the outset*" that the endeavour is supported at a university level.

Presenting the need for change to faculty: Many interviewees noted that the initial meeting with faculty to introduce the idea of educational change is a "*make or break*" point in the process. As one interviewee commented "*this is all about faculty time, and winning them over is a combination of convincing them that the change effort is sufficiently beneficial that it requires their attention and reassuring them that the endeavour will not significantly eat into their time*". During this initial meeting, many of the leaders of successful changes focused discussions solely on the underlying drivers for change – "*do not present the solution before anyone has had time to think about the problem. People then just look at the implications it has on their own teaching and never really engage with the problem*".

Phase 2: Planning for the change

Selecting the new educational model: Once the decision had been made to embark on a programme of systemic change, the selection of the underpinning educational approach is often "*a relatively quick and painless decision*" based on a brief international benchmarking exercise or the "*classroom experience*" of those leading the change. One striking feature of the interviews was the similarity between the educational goals of the reform efforts described, regardless of geography or institution type. A significant majority of successful change programmes "*develop[ed] our own unique approach, that blends problem-based learning with professional engineering practice*". In almost all cases, a clear emphasis is apparent on the unique and bespoke nature of the educational approach adopted.

Curriculum design: Many interviewees talked about the importance of engaging the majority of, if not all, faculty in the process of designing the new curriculum. This process was seen to be critical in both optimising support for the change effort and ensuring that the reformed programmes would be sustainable. This process was most effective when faculty were able to take a step back and think fundamentally about the curriculum from a blank slate, rather than "*tinkering at the edges*" of the existing curriculum. In many cases, the widely acknowledged urgency of change supported this fundamental re-assessment. Some interviewees, particularly from Scandinavian countries, spoke about the value of faculty development workshops and their role in informing the curriculum design process.

Careful planning by a small management team: Many change leaders spoke about the importance of careful and methodical planning, undertaken by a "*safe pair of hands who knows the department inside out*". Building on an intimate knowledge of the faculty, learning spaces, resource availability, these individual/s would develop plans for the transition to and on-going operation of the new curriculum.

Resourcing: The injection of new funding into a change effort is relatively rare, and does not appear to be a particular characteristic of successful programmes of change. However, almost all successful changes 'bought-out' a small portion of the time of at least two carefully-selected individuals. Typically, this funding is sourced internally, usually at the departmental/School level. A very clear divide was apparent between the US and all other countries considered in this regard. In sharp contrast to non-US interviewees, those individuals consulted from the US were significantly more likely to consider external funding as an essential factor in successful change.

External perspectives. As noted in Section 3.4.5, many programmes of change appear to be initiated at School/departments with significant numbers of newly appointed faculty or high numbers of faculty with industry experience. Where these factors did not apply, leaders of successful change talked about the importance of bringing in a "*fresh pairs of eyes*" to the planning process, typically employed on a temporary part-time basis. The types of individual selected vary by institutional culture and geography, but most have a background in either engineering industry or education.

Phase 3: Implementing the new approach

Establish an implementation team: Interviewee feedback on implementation focused on *who* should be making the changes and *how* they should be supported by their department or School. To avoid "*burn-out*" of those charged with implementing the changes, many interviewees recommended ensuring that other departmental duties be formally removed from these individuals during the period of reform. Caution was also advised in the selection of the early adopters of the new approach – "*they must not just be the 'usual suspects' of mavericks that people have become accustomed to ignoring*".

Demonstrate the benefits of the change: In the months following initial implementation of a reform, many interviewees reported a period of "*exhaustion*", where some faculty "*question whether it is all worth it*". Some interviewees noted the value of "*demonstrat[ing] the benefits of what we were doing – Show that academics are accepting it. Show that someone has been promoted as a result of it. Show that it was starting to have a positive effect on students*". Such activities are seen to maintain the momentum of the change during a "*very intensive and time-consuming period*".

Implementation speed and phasing: There did not appear to be a common pattern amongst the successful reform endeavours with respect to piloting the reform; some piloted and refined their approach extensively over a period of 2–3 years before rolling out widespread change, while others trialled the new approach in a single course and started full implementation within a year. However, what was common across successful change efforts was the manner in which they moved from the pilot/conceptual phase through to roll-out. Sustainable, widespread change was very rarely associated with a gradual expansion, where courses were slowly reformed one at a time over an extended period. Although exceptions clearly exist, most successful, systemic changes were implemented in a single concentrated and focused effort over a 2–4 year period, and called for considerable faculty-wide attention during that period. One reform leader described this as "*taking the band-aid off quickly*". It should be noted, however, that the overall reform process (from initial planning to impact analysis following implementation) rarely took less than five years and typically took much longer. As one interviewee noted, "*be prepared for a long term endeavour. Whatever people say, this will not just take two years!*".

3.5.3 Common features of unsuccessful change

As with any other process of change, the majority of reform efforts in engineering education fail. Many interviewees described their own personal experiences with failed reform efforts, both as the instigator of change and as an observer. On the basis of the interviewee responses, there appear to be three critical stages when failure is most likely to occur, as outlined below.

- Point 1: immediately following the announcement to faculty of the intent to change;
- Point 2: very early in the implementation process;
- Point 3: 5–10 years following full implementation.

The types of failure commonly reported at each of these three stages are summarised below.

Point 1: The key cause of early failure appears to be where the champions for change are "*unable to articulate the benefits that it will bring*" and faculty are left unclear as to "*what is happening and why*". Some interviewees spoke about a "*disastrous*" early meeting with faculty, where the concept of educational change was first introduced, after which "*the academics revolted before they even started to implement this*". One interviewee recounted the aftermath of such a meeting, where a senior faculty member "*made it very clear to the Head of Department, that, if this change went ahead, all of his best* *academics would leave. This risk was just too great*" and the reform was abandoned. In particular, if faculty view the reform as "*dumbing down*" the engineering fundamentals within the curriculum or as not aligning with the strategic priorities of the School or university senior management, "*it will be rejected instantly*".

Point 2: A common point of failure appears to be early in the implementation process. The majority of issues appear to relate to a lack of resources. For those who benefitted from external funding to support the change, some noted that "*the money runs out before anything has been truly integrated*" and the activity is not sustainable. Many of these examples continue to "*look successful from the outside*", although very little real change has been made. For others, only minimal resource was ever devoted to the change. The planning and early implementation stages were completed through the "*good will and hard work*" of a small number of dedicated faculty, but they were unable to devote this level of effort (in addition to their existing duties) for a sustained period. One interviewee spoke about the impact of such under-resourcing, "*This is okay for the first year or so, until they get burnt out by years 2 and 3, usually just as you are starting to roll the changes out into the curriculum. We had this problem, and we had a lot of people become ill in this period*". Without the steady drum beat of someone saying "*let's do this, let's do this, let's do this..*", momentum is lost, with the result that that changes "*never really got to the heart of the curriculum and then just faded away without anyone really noticing*".

Point 3: The third point at which failure appears more common is in the years following full implementation of the change. This issue is discussed further in Section 3.6.1.

3.6 Sustaining and evaluating change

3.6.1 Sustaining change

A high proportion of educational reforms that have been successfully implemented appear to encounter significant problems in sustaining the change. Indeed, of the curriculum reforms investigated that had been operational for more than 10 years, almost all had encountered a significant, and in some cases almost catastrophic, problem that threatened their sustainability. Many interviewees recounted similar experiences in this regard. The common triggers for the non-continuation of reforms were staffing/organisational changes such as the appointment of a new Head of Department, retirement of the original change leader or a School-wide restructure. Following these disruptions, it appears that those changes that have been implemented into the *core* curriculum are much more likely to "*survive*". In other words, at these points, sustaining newly-implemented extra-curricular, optional or pilot courses have a much lower success rate. Rather than an abrupt abandonment of reforms, interviewees tended to describe a cumulative dilution of the changes, leading to a lack of coherence to the approach and a "*drift*" back to something closely resembling the prior curriculum.

The underlying issues seen to undermine the sustainability of reform were:

- the changes continuing to be 'owned' by one individual;
- the changes remaining isolated within the curriculum;
- faculty and senior management becoming focused on other activities ("*took their eye off the ball*")
- a lack of meaningful evaluation data;
- a lack of informal positive feedback;
- the new curriculum never becoming formally recognised as the 'standard' approach.

Each of these issues is discussed below.

Faculty ownership: In many cases, the underlying cause for failure appeared to be that the change was predominantly 'owned' by one individual, or small group of individuals, and its long-term success continued to rest on their shoulders. Typically, this individual would deliver many of the flagship courses in the reformed curriculum and devote very significant time and effort to their teaching activities. As such, they would be widely seen to have jeopardised their research profile, and thus career progression, in order to deliver the new curriculum. One interviewee commented that "*we need to set the bar lower for what innovative engineering education looks like. The more you build up the 'ideal' instructor, the less likely you are to build capacity… People need to know that you don't have to kill yourself [to deliver non-traditional educational approaches]*". For some, the answer lay in the development of a team teaching approach across all non-traditional courses, with regular rotation of faculty involved, particularly amongst new faculty. By widening the net of individuals who could deliver the reformed courses, the sense of individual ownership would be reduced, as would the expectation that faculty would need to devote unrealistic time and energy to the activity. Many interviewees talked about the positive, but subtle, changes that occurred within their departments following the introduction of team teaching – "*teams of three worked closely together, and started to share tips and take an interest in each other's teaching. The conversations suddenly started to change in the coffee room, as people actually started to talk about their teaching*".

Isolation within the curriculum: Where the original reform was not part of a strategic analysis and re-design of the curriculum, the resulting changes are often isolated with few, if any, meaningful linkages to 'core' courses. As such, most faculty are often not aware of the changes made or the impact that they may have on student learning. However substantial or successful the changes themselves, such reforms are highly vulnerable to university re-structuring (having not generated a wide support base to champion their continuation) and faculty turnover (with few faculty willing or able to pick up the delivery of the courses).

Maintaining a focus on education: A number of interviewees who have been involved in department-level reforms commented that the sustainability of larger-scale reform was contingent on a culture of continuous change and improvement – "*after the first cohort of students graduate from your new programme, the tendency for staff is to 'hang up* *their boots' and settle back to a focus on their research. This can be very damaging, as elements will start to drift back to the old curriculum, and others will just stagnate. You need to ensure that a core of the staff are really engaged in continuous change and development*". Some also spoke about how newly-appointed faculty often do not appreciate the importance of maintaining the changes – "*the new faculty were not there when we were about to be shut down and never felt that pressure*". A number of different mechanisms were suggested for stimulating this process of continuous change. For some, particularly US-based interviewees, this was only possible through the injection of ring-fenced funding for innovation and research in engineering education. Other mechanisms which were found to maintain engagement included the establishment of internal research groups in engineering education.

Informal positive feedback: Maintaining change is clearly much more problematic where faculty do not see or feel the positive benefits of the reforms. Without individual faculty members hearing direct and positive feedback, motivation levels for sustaining a reform often diminishes, particularly where overall workloads have increased as a result of the change. Amongst those change programmes that have been successfully sustained, two features are often apparent, either singly or in combination. Firstly, faculty across the department/School are aware of a significant increase in student motivation and intake quality which they directly attribute to the reform, whether or not they were originally supportive of the changes. Secondly, the existing or newly-established Industry Advisory Board takes an active role in supporting and overseeing the undergraduate curriculum, providing positive feedback on the reforms that is "*heard*" by individual faculty.

Impact of the changes: Well-designed impact evaluation plays an important role in sustaining change, as discussed in Section 3.6.2. Impact evaluations appear to be particularly valuable in protecting a new curriculum during periods of re-structuring and staff change – "*If the new management does not like it, especially if you can't provide evidence of its success, people will revert to the status quo*."

Formal acknowledgement: Finally, a number of interviewees commented that curriculum changes often "*become diluted*" where they are not formally acknowledged as standard School/departmental practice, and remain operating with "*the status of a long-term pilot innovation*". Some noted that an explicit, and formalised, signal that an educational change was now part of the permanent curriculum was "*the key to long-term success*". Examples offered included the inclusion of the new course/experience in the student handbook or the activity becoming a "*line in the departmental budget*".

3.6.2 Impact evaluation

The study has focused on identifying the common features of programmes of positive and long-term educational change in engineering. Amongst those reform endeavours considered, it was apparent that formal impact evaluation was more common amongst changes that had been sustained. In particular, where significant problems had been encountered in sustaining change, impact evaluations appeared to play a crucial role in overcoming them. Despite these apparent benefits, however, systematic impact evaluations of systemic educational changes are relatively rare. Where evaluations had been undertaken, most tended to be hastily conducted and incomplete, and almost all required a bespoke assessment model to be developed in-house. These observations were supported by many of the researchers in educational change consulted – "*There is a very low bar when it comes to evidence. It is very anecdotal. People tend to present quotes from a small number of programme supporters as evidence. Other evidence was not really meaningful, such as a [student] exit survey*". Indeed, few interviewees could identify any impact evaluations from educational change programmes that they felt were well-designed and rigorous. Two of the exceptions were the evaluations of the programme-wide reforms in the School of Civil, Environmental & Chemical Engineering at RMIT in Australia and the reforms of the introductory physics course in the Department of Physics at the University of Illinois in the US, which were both recommended by a number of interviewees.

There appear to be a number of reasons why rigorous impact evaluations are so rarely conducted. These issues are outlined below.

- ***No clarity about <u>what</u> to measure:*** The difficulty in measuring the impact of educational change was a common theme in the interviews, as was the lack of commonly accepted models for such impact assessments. Another issue highlighted was the lack of clarity about the underlying goals of the reform, which made impact assessment almost impossible – "*for many people, the success criteria they talk about are much more grand that it will ever be possible to evaluate, and they can ever attribute solely to the change they are making*".
- ***Measurements starting too late.*** Many Schools/departments do not start to consider impact assessment until well after the process of implanting change has commenced – "*People often develop new metrics at the 2nd or 3rd year of the change implementation, which is too late*." By this stage, it is almost impossible to collect 'base-line' data to capture curricular impacts before the change, and therefore draw any firm conclusions about the long-term impact of the reform. One exception in this regard, is Aston University in the UK, which is just embarking on a 7-year longitudinal study of the impact of an upcoming change to the engineering curriculum.
- ***Responsibility falls on one individual.*** The responsibility for impact studies is typically taken by one individual, often the person who has carried much of the burden of the change effort itself. As this task is undertaken in addition to many other duties, the data collection is often rather "*haphazard*" and stored in a manner that makes it difficult for others to retrieve or interpret. Some interviewees estimated that, for impact data to be meaningful, it must be collected over the course of at least 10 years, from before the change is implemented through to the point where the first

graduating classes are operating in the workplace. When relying on one, typically over-stretched, individual, ensuring continuity over such a long period is very difficult. In practice, the individual will often retire, run out of the original project funding or feel that they must "*get on with their day job*" at a relatively early stage, and data collection essentially stops at this point.

4 Evidence from the case study investigations

This chapter investigates the process of educational change in six Schools or departments of engineering from across the world. Reflecting the focus of this report, these investigations centre on *how* change has been achieved, rather than *what* changes were made and/or the efficacy of the underlying educational approach adopted.

The case studies were identified through the interview phase of the study, as outlined in Chapter 3. All those interviewed were asked to identify examples of engineering education reform that they have been impressed by or considered to have been particularly successful. The 6 case studies were selected from this set of examples (as listed in Figure 4), as a mechanism to improve the likelihood that they described change that was both genuine and effective. They were also selected to provide a spectrum of drivers for reform, change strategies, levels of ambition, geographical locations and stages in the change process. The case studies all involved planned, systemic change that impacted (or had the potential to impact) a significant proportion of the core engineering curriculum.

The case studies selected for investigation are listed below.

1. The Department of Civil, Environmental & Geomatic Engineering, Faculty of Engineering Sciences, UCL, UK
2. School of Engineering, Hong Kong University of Science and Technology (HKUST), Hong Kong
3. iFoundry, University of Illinois, US
4. Department of Chemical Engineering, University of Queensland, Australia
5. Faculty of Engineering and Computing, Coventry University, UK
6. Learning Factory, Penn State, US

Figure 5 illustrates the broad timelines over which these reforms have been implemented, with the date of the case study investigation process (April–September 2011) indicated with a dashed red line. As can been seen from the figure, three case studies presented have completed the change process and three are still on-going.

A total of 128 individuals were consulted for the case study investigations, including 64 one-to-one interviews. For each case study, formal interviews were held with between 8 and 17 stakeholders and observers to the educational programmes. Interviews were typically 1-hour in length and conducted either face-to-face or remotely, via Skype or telephone. Interviews were complimented by additional evidence gathering through informal feedback sessions and focus groups. In addition, classroom observations were undertaken for all but two of the case studies – the University of Queensland, where the author had observed the reformed curriculum on a prior occasion, and the HKUST where the educational change is yet to be implemented. All case study evaluations were approved by the host university concerned before their inclusion in this report.

The six case studies are presented in the sections that follow.

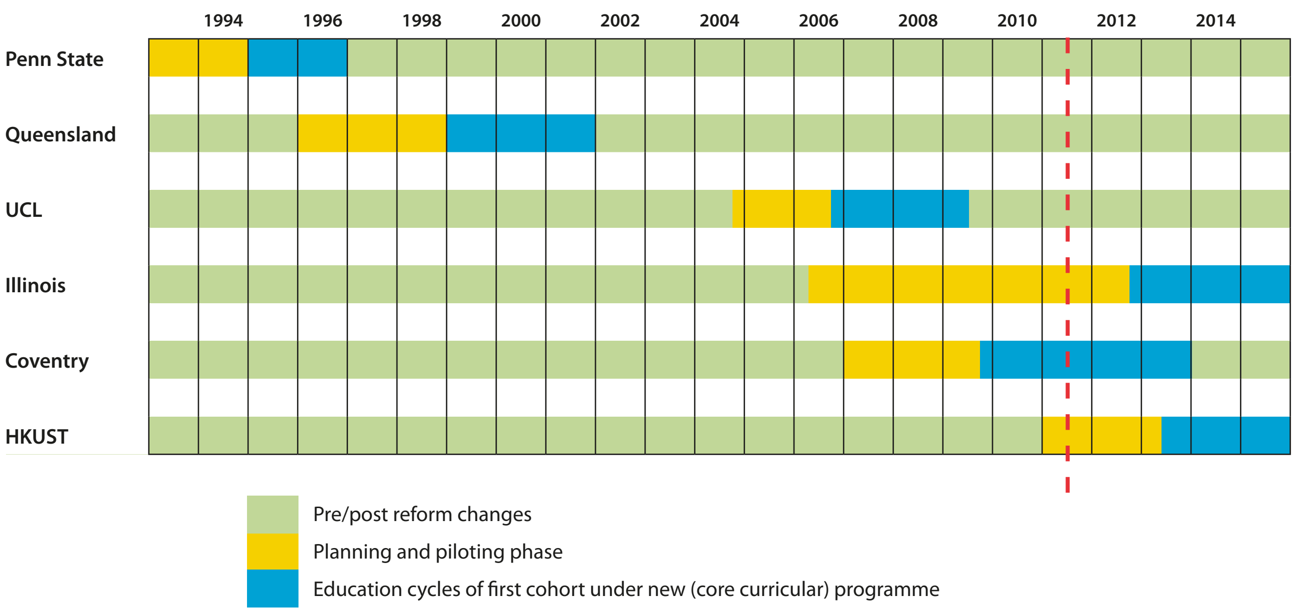


Figure 5. Time lines for change of the 6 case studies investigated. The time of investigation is indicated with a red dashed line.

4.1 Case study 1: Department of Civil, Environmental & Geomatic Engineering, Faculty of Engineering Sciences, UCL, UK

Overview: This UK-based case study describes a department-wide reform involving a significant re-design of the first two years of the curriculum and a controversial change to entry requirements. Initial discussions on the reform effort started in 2003 and the first cohort graduated from the new BEng (3 year) curriculum in July 2009.

Reasons for selection as a case study: (i) this department-wide change was undertaken within a premier research-led institution, (ii) despite a controversial broadening of the entry requirements to the degree programme, accreditation was granted, (ii) the model for change is to be rolled-out across a number of other departments within the School[3].

Who was interviewed: 21 individuals were consulted for the case study investigation. Informal discussions were held with 11 current departmental undergraduates (selected at random from the 1st, 2nd and 4th years of study) and formal interviews were held with 10 other stakeholders to the undergraduate programme (including the current Head of Department, current and former Director of Studies, faculty from both the Department of Civil, Environmental Geomatic Engineering and other departments in the School, the Vice Dean (Education) for the School, the university Vice-Provost, the Director of Membership and the Institution of Civil Engineers, and a member of the department's industry advisory panel).

3 For consistency across all case studies, 'School' in this case will refer to the Faculty of Engineering Sciences

4.1.1 Context and drivers for change

Context: UCL is a London-based university with very strong international research reputation. It is seen to be an institution that encourages "*mould-breaking and rapid*" change, a vision supported at a senior university level. For some, the UCL operating model is more akin to a corporation than a university, resulting in more decisive change, with strategic decisions often made by individuals rather than committees. Departmental structures are strong, with limited exchange between departments on educational ideas and approaches.

The Department of Civil, Environmental & Geomatic Engineering (CEGE) is one of nine departments in the School, and is home to around 40 faculty with a current undergraduate intake of around 70 students each year. The current Head of Department has been in post since 2003. Prior to the reform effort, CEGE was seen to be a "*fairly typical research-intensive engineering department... with very few changes made to the undergraduate programmes in over 30 years*". Indeed, one described the department's educational approach as "*as traditional as they come – very old school*". Although some non-traditional teaching and learning approaches had been employed prior to reform, these were largely confined to design teaching and not typical of the wider departmental practice. The demographic in the department was strongly male, with many faculty close to retirement.

Drivers: The principal drivers for the change to the undergraduate education in CEGE were problems with recruitment and student engagement – "*the poor quality of students coming in [to the department] and the problem of them becoming very demotivated by the second year*". These issues were highlighted in an external examiners' review of the degree programmes, which pointed to a low 'value-added' between student entry and exit.

A number of other issues were also apparent. Within the department, there was a feeling amongst a number of the faculty that the undergraduate programme was no longer 'fit for purpose' and did not adequately respond to the societal, environmental and political challenges of the 21st century. Indeed very few changes had been made to the core curriculum in more than two decades. The department's research profile was also not aligned to subject areas taught at undergraduate level, resulting in a very uneven teaching load across the faculty.

In response to these problems, the new Head of Department was appointed in 2003 with an explicit mandate to 'turn around' the undergraduate programme. Other staffing changes followed. The new Head of Department undertook a rapid recruitment programme, appointing 10 new faculty to replace those close to retirement. A high proportion of the new faculty were young and female. With these appointments came a significant shift in the department's age and gender demographic, and an accompanying change in departmental outlook and culture.

4.1.2 The educational vision and changes implemented

The incoming Head of Department instituted a fundamental review of the undergraduate programmes to develop a new vision of "*what we are really trying to achieve*". To articulate their vision and goals, the review considered *both* inputs (student profile at the point of admission) and outputs (skills, knowledge and outlook at the point of graduation). The review therefore evaluated the desired demographics, aspirations and attitudes of both incoming and graduating students. It was informed by consultations with both schools and engineering industry. Only very limited external benchmarking of alternative educational approaches was conducted and no reference was made to existing research on effective pedagogies in engineering.

The consultations with schools identified a number of important markets that were being 'missed' by the department's current undergraduate recruitment – principally highly gifted and academically able individuals who would be engaged by the challenge of an engineering education, but were not necessarily motivated to become engineers. This group were seen to be driven by a desire to "*fix the world and make it a better place to live in*" and typically would not be studying Mathematics and Physics at A level (which would usually be mandatory for an entry to a UK engineering degree programme). A key message emerging from the consultations with industry was the particular need for strong engineering leaders and problem-solvers, with a broader educational base.

Reflecting the focus on *inputs* and *outputs*, the major changes related to *recruitment* and *educational approach*:

- ***Recruitment:*** The admissions criteria were broadened, to accept prospective students studying *any* A-level or equivalent on entry to the programme, provided that they achieve at least 'straight A-grades'. Interviews for entry to the programme were replaced by a team-based PBL (problem-based learning) scenario. The marketing of the programme was refocused around the themes of *leadership* and *engineering for social responsibility*.
- ***Educational approach:*** The first two years of the curriculum has been redesigned and now operates in 5 week cycles. The first four weeks of each cycle is delivered in a largely traditional manner, but is structured around four equally-weighted 'clusters' – *context*, *mechanisms*, *tools* and *change* – rather than the traditional engineering discipline-based topics. Given that only two of the 'clusters' (*mechanisms* and *tools*) stem from engineering science, the traditional engineering curriculum content has been significantly reduced. A greatly increased emphasis has been given to topics such as *design* and *conceptualisation*. The final week of the cycle is a full-time intensive, team-based problem-based learning 'scenario', where the problem posed draws on the learning from the preceding four weeks.

The reforms also delivered three major operational benefits: (i) 50% reduction in contact hours, thus allowing faculty time for planning, delivery and assessment of the PBL-style scenarios without increasing the average teaching loads, (ii) a more equitable distribution of the teaching load across all faculty, regardless of their area of research specialism, and (iii) a reduction in the number of degree programmes from 12 to 2 – the *Civil Engineering* and *Environmental Engineering* programmes.

4.1.3 Achieving change

As noted above, change was initiated by the appointment of new Head of Department in 2003, followed quickly by the recruitment of new faculty and a root-and-branch review of current provision in order to develop a new vision of the undergraduate programme. Key elements of the vision were to provide a broader, more engaging curriculum, based around problem-solving, that attracted bright, creative and socially-responsible individuals who could rise to leadership positions both within and outside the engineering profession.

Following agreement on this educational vision, two attempts were made to design a new curriculum capable of delivering it. The first 'bottom-up' approach to the educational reform did not succeed (Oct. 2003 – Oct. 2004). The second attempt, which combined a 'top-down and bottom up' approach, was successfully designed and implemented (Oct 2004. – Sept. 2006). The full change process, including both of these attempts, is outlined below.

Initial discussions among departmental senior management on the 'bottom up' approach began in summer 2003. In October 2003, a working group, comprising faculty with an interest in educational change, was established to review the existing curriculum and to re-design the educational provision in the first two years of the undergraduate degree. In July 2004, the working group presented their proposals for education reform to all departmental faculty, with a curriculum structure that was largely based around the traditional engineering science disciplines. The proposed reforms met with significant opposition, both from those who saw them as "*dumbing down*" the engineering science elements of the education, and those who viewed the change to be "*too conservative and too close to what we already had*". At this point, it was recognised that a new approach to the change process was needed – "*the bottom-up approach was too meandering. We actually needed to be forced to think about the education in a completely different way. So Nick [the Head of Department] swung in with an edict*".

A new approach to the change process was adopted in October 2004, when the Head of Department fundamentally redesigned the curriculum structure and then asked all faculty to engage in the new curriculum design. One of the most significant changes made by the Head of Department was to move the curriculum away from the traditional engineering disciplines and reshape it around four 'clusters' and project 'scenarios'. Working groups were established for each of the four cluster themes; all departmental faculty were allocated to a working group and tasked with designing that element of the curriculum. In January 2005, the educational vision and curriculum template were presented to senior university management and given provisional approval to proceed. The educational approach, including the plans to broaden the entry criteria for incoming students, was also informally discussed with the key Civil Engineering accreditation agency at this stage, to a very positive reception. Following further development of the approach and curriculum design by the four working groups, a 'dry run' of one of the scenarios was held in July 2006. Two months later, in September 2006, the first cohort of first-year students entered the reformed programmes.

4.1.4 Critical factors in successful change

Four elements appear to have been critical to the success of the change process:

1. Strong and committed leadership;
2. A clear vision for the educational changes, which was well communicated to faculty, senior university management, industry advisors and the accreditation agencies at an early stage of the reform process;
3. A clarity amongst faculty that significant change was

going to happen – "*we knew that this was not going to go away, so we really needed to engage with it*";
4. A curriculum that was designed by all faculty, but through a process that required them to think outside their discipline areas.

Each of these elements is discussed in turn below.

Strong and committed leadership. This was provided by a well-respected and dynamic Head of Department with strong backing from senior colleagues in the department and the university. The Head of Department has a strong international research reputation ("*his research record speaks for itself*"); he also has a personal commitment to the undergraduate experience and devotes significant time to teaching. Both those within and outside the department pointed to a step-change that occurred when the Head of Department took up his post, of which the reforms to the education were one part. In the atmosphere of a changed faculty demographic and a new energy from the top, a cultural shift was seen to take place, with a new openness to discuss educational change. It is also clear that, while the Head of Department provided the vision and leadership for the reform, its implementation was managed by two key faculty members, one of whom was the Director of Studies at the time. For many, this combination of strong and passionate leadership, on the one hand, and systematic and careful curricular implementation, on the other, provided the conditions in which successful change could be achieved.

A clear vision for change ("*the intellectual case was superb*"). All stakeholders, both within and outside the department, were able to articulate the educational vision, and used similar terms to describe it. It was acknowledged to be a fundamental, but carefully considered, reform, presented (by the Head of Department) with passion, precision and complete confidence in its success. The messages resonated well at all levels, with clarity both about the goals and targets for change. For example, the drive for leadership and social global responsibility embody elements of the university's wider vision for undergraduate education. A number of the proposed changes – such as the broadening of the entry criteria – were controversial, but the articulation of a strong narrative for change helped to secure support for them. The vision was also seen to be addressing a number of fundamental concerns about UK engineering education, such as how to widen participation in engineering, particularly amongst girls, and how to improve the leadership position of UK engineers in an increasingly globalised industry. For some, the radical and fundamental nature of the change also held strong appeal – as the Head of Department in CEGE commented "*the big advantage of [the change in] our department is the image was associated with 'making the world better'. That marriage – what they are trying to do being bigger than the subject – may be more difficult in other disciplines*".

Change is inevitable. From the beginning of the change process, the Head of Department was clear that a significant change was coming and that reform would be rapid and fundamental – "*You can't do this by tinkering at the edges. I didn't give them any options. There needed to be a fundamental change, and it needed to be a quick hit*". The early discussions with the university senior management, the Vice Provost of UCL, and the key accreditation agency for the programmes, the Institution of Civil Engineering, also appear to have been very significant. The radical nature of the proposed changes always carried a danger of being dismissed by faculty as unworkable or unlikely to be supported by the university or accreditation agency. Securing support at such an early stage from both the university and the accreditation body "*caught many of the staff off-guard*", helping to diffuse much of the early resistance to reform as well as demonstrating the seriousness of intent to push forward with change. As one faculty member commented "*Once Nick [the Head of Department] had sold the vision of what we were trying to do, we had support right up the chain of the university, the Vice-Dean, the Dean, the Provost and even the ICE [the key accreditation agency]. After this, it was quite hard for people to pretend that this was not happening*".

An inclusive process of change. All faculty were given a voice in the design of the new curriculum, through their assigned 'cluster' working group. However, although the curriculum was developed by departmental faculty, they were not able to operate within their traditional engineering disciplines. Instead, because each working group theme cut across disciplines, faculty were "*forced to think about the curriculum from a blank sheet, rather than just fighting for their own subjects to continue*". The early stages of the change process uncovered divisions among faculty about the magnitude of change that they were willing to support; some were pushing for a wholesale problem-based learning (PBL) approach across the curriculum while others believed that the curriculum should remain entirely unchanged. In many ways, the creation of the 5-week cycles "*made everyone feel that they were getting what they wanted – the PBL group had their focused intensive periods and the traditional group could just operate in the 4 out of the 5 weeks where they could deliver the courses in any way they chose*".

4.1.5 Challenges in the change process

A number of challenges were encountered during the design, implementation and continuation of the educational changes in CEGE. An early practical challenge was running the old and new curriculum concurrently for 2 years. But the major challenges for the management of the change process appear to relate to faculty attitudes and values.

The most controversial element of the reforms was the removal for the requirement for entrants to have studied Mathematics and Physics during their previous two years of school (A-levels or equivalent); as one faculty member commented "*convincing the staff to accept this was this was the biggest challenge for the department*". These changes are now broadly accepted by departmental faculty, primarily because the concerns that fuelled opposition to the changes have proven to be unfounded. The first concern was that such changes would lead to non-compliance of university/accreditation regulations; to address this concern the widening of the intake was discussed, and explained, at an early stage with university senior management and the critical accreditation body, leading to strong support in principle in both cases. The second concern was that there would be a reduction in the quality and mathematical abilities of the student entry. Instead, the changes resulted in dramatic increase in the overall quality of student intake, and the non-traditional intake, in particular, were outperforming their peers in the mathematically-based subjects.

A second challenge concerned a difference of view on the goals of the undergraduate programme. A number of faculty expressed concern about the shift away from educating future engineers and towards developing leaders who can operate across different professions. In most cases, these concerns do not appear to have been allayed, with a number of individuals still strongly believing that the change was mis-guided; in their view, the education and training of professional engineers should remain the primary goal.

Finally, although a large part of the curriculum design was undertaken and 'owned' by departmental faculty, it also clear that much of the change process was mandated at Head of Department level, and, in that sense, had a strong 'top-down' element. This has clearly caused some problems, leaving a number of faculty with the feeling that they "*did not get a fair hearing*" when expressing their ideas or concerns. During the process of change, the Head of Department was not seen to engage with those more resistant to change. Although this does not appear to have altered the course of reform, for some, this has left some "*simmering issues*" within the department that "*may come back to bite us once the Head of Department is replaced*".

4.1.6 Impact of the changes

There is compelling evidence of improvements in intake quality, retention rates and student performance following completion of the reform programme.

Student intake. Over the past 10 years, the department has seen a dramatic improvement in the academic standard of incoming students, with A level entry grades rising from CCC in 2003 to AAA in 2011. Although other departments in the School have also seen increases in intake quality during this period, the rises in Civil, Environmental and Geomatic Engineering have been much more significant. During the early years of the reform, the department experienced a decline in the application numbers from overseas students, which was presumed to stem from the shift away from a traditional education in the engineering fundamentals. However, over the past 2 years, the numbers of applications from overseas students, particularly those in China, have increased significantly. This shift is seen to be due, in part, to the reputation of the reformed education, but also due a broader improvement in the international profile of UCL and the wider engagement, particularly in China, with the need to integrate personal and professional development into engineering education.

Student Performance. The curricular changes appear to have triggered a significant improvement in the end of year scores achieved by students. For example, Figure 6 illustrates the increase in the percentage of high-achieving students following reform and Figure 7 illustrates the decrease in percentage of students with low performance scores following reform. These figures were created from attainment score data spanning 2002–2010.

Most telling, perhaps, are the improvements in achievement level apparent in the third year of study, where both the curriculum and assessment approach have remained unchanged. The numbers of third year students achieving the two highest attainment classifications rose from 43% (prior to the reforms, from 2001 to 2008) to 60% (following the reforms, since 2008). In addition, the numbers of students achieving the three lowest attainment classifications during their third year decreased from 23% (prior to reform, from 2001 to 2008) to 8% (following the reform, since 2008).

Widening participation. The number of students entering the programmes by the non-traditional route (i.e. those not studying Mathematics and/or Physics pre-university) has been relatively modest – less than 10% of the cohort each year. However, almost all of those consulted within the department, faculty and students, commented on the disproportionate impact that this group has on the cohort as a whole, acting as a catalyst for improved creativity, enquiry and ambition – "*they ask more questions about the background and context of problems. They are particularly hard-working, as they feel they have to make up ground in maths and physics, and this effort is infectious*".

The student experience. Informal discussions with undergraduates as part of this case study revealed strongly positive attitudes to the new educational approaches, particularly the 'scenarios', which were seen to be intensive, challenging but highly beneficial. The comments of one second year student were very typical – "*we live from one scenario to the next…. They are really 'full-on'. You know those weeks are going to be really exhausting, but you are so aware of how much you are learning. They [the scenarios] are really important*". The key concern amongst the students centred on the operation of the scenarios rather than the model itself. They pointed to a lack of consistency in approach to each scenario, apparently stemming from poor communication between faculty members, and, in a number of cases, a lack of timely and informative feedback following the scenarios. It was also interesting to note that only those undergraduates with non-traditional entry into the department were aware of its radical educational approach in advance of the departmental open day or even entering the first year. In other words, the department does not appear to be actively marketing itself as effectively as hoped. This issue was also highlighted by a member of the department's industrial advisory committee – "*there is no clear indication, externally, that the course is different. They are really underplaying the virtue of what they have*".

Faculty experience. Faculty feedback on the impact of the reforms is also broadly very positive. In particular, the increase in student quality and engagement has been a major motivation for faculty. A number highlighted the differences they see in recent cohorts of graduates, with enthusiastic feedback from employers and an increase in external prizes and awards in national student competitions. Some continuing concerns exist amongst a small number of faculty over the reductions seen to the traditional engineering science content in the curriculum. However, these concerns are not widespread and appear to be diminishing with time.

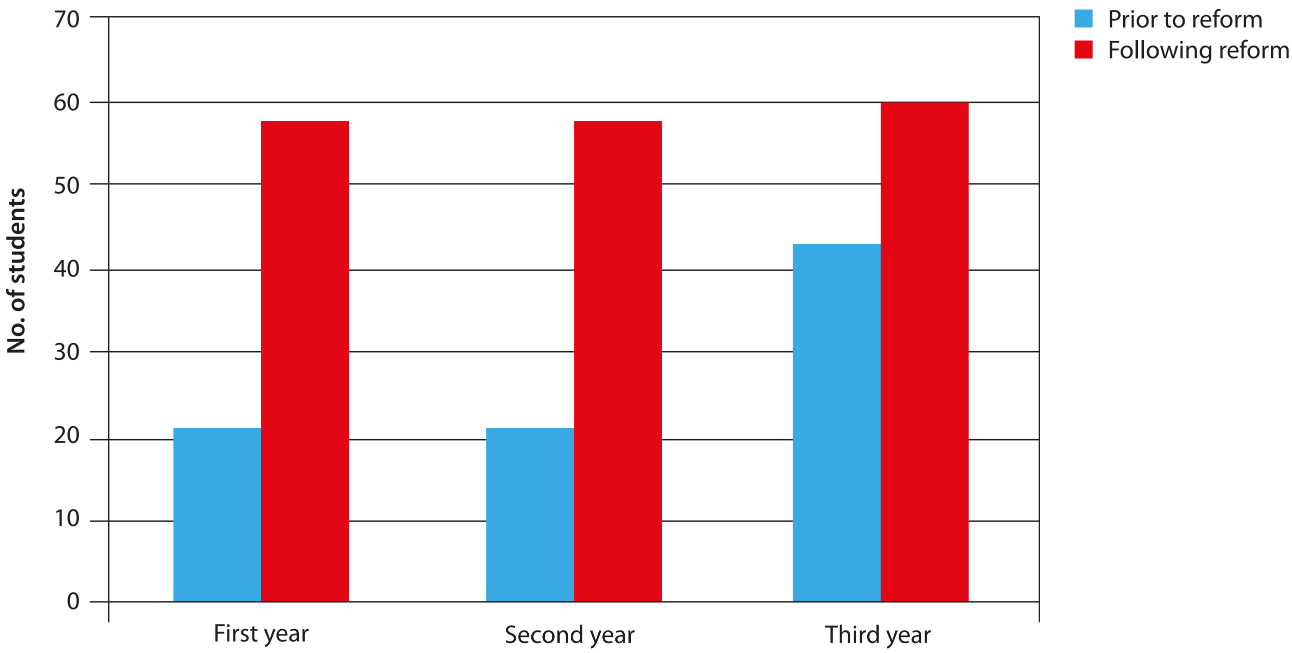


Figure 6. Percentage of students achieving the two highest attainment classifications (1st and 2:1), comparing average scores before and since reform was implemented in that year of study. Data taken from attainment score from 2002–2010.

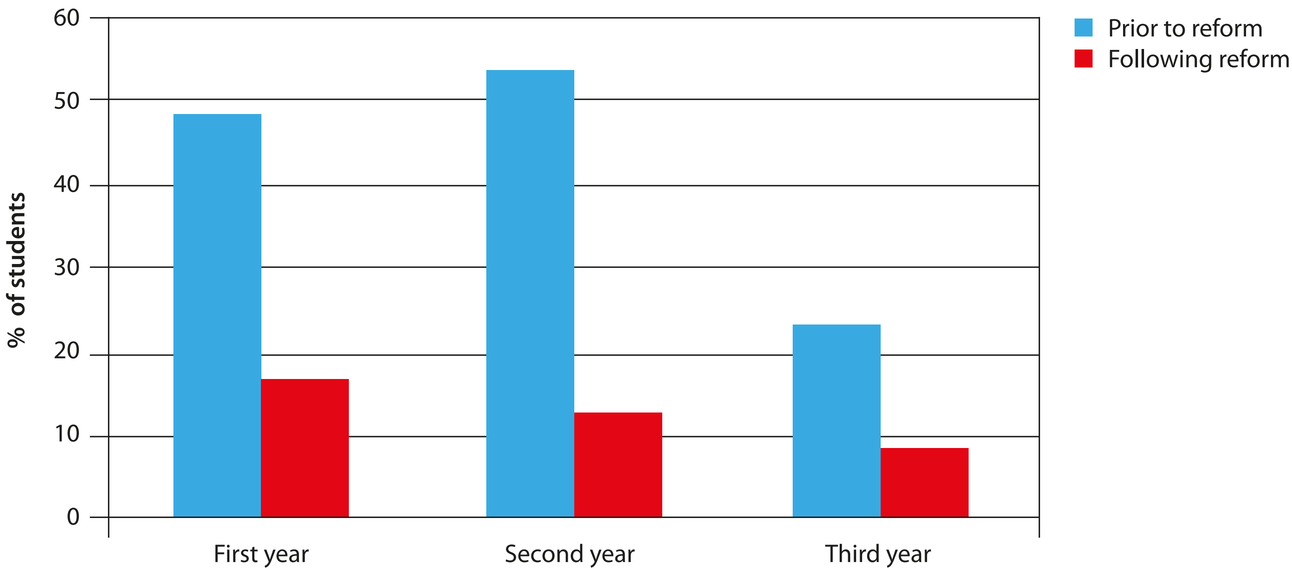


Figure 7. Percentage of students achieving the three lowest attainment classifications (3rd, ordinary pass and fail), comparing average scores before and since reform was implemented in that year of study. Data taken from attainment score from 2002–2010.

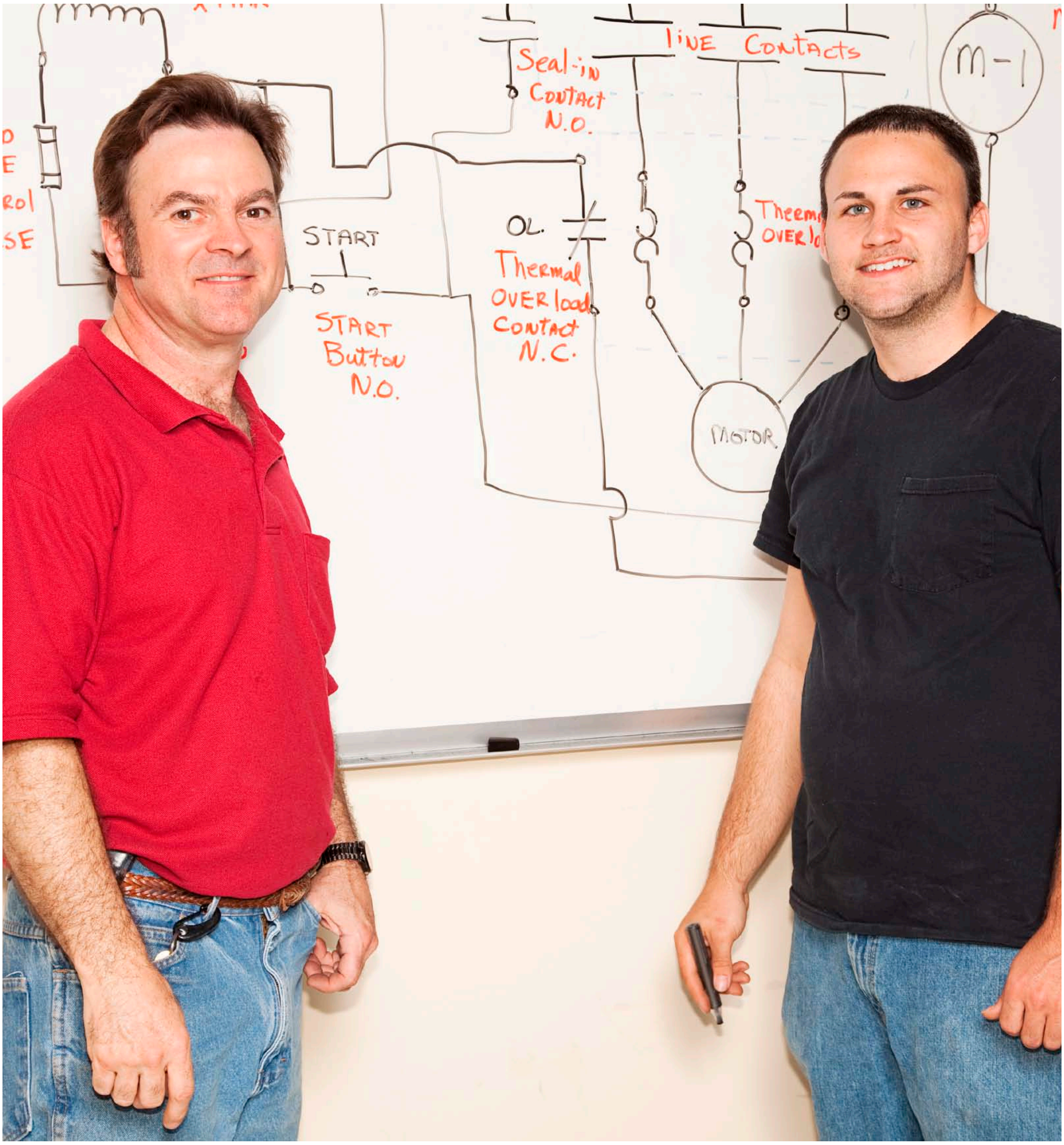
There were mixed views about the impact of the reforms on overall faculty workload. Some faculty pointed to an increase in the overall 'teaching load' resulting from the reforms, which were not seen likely to reduce, even when 'steady-state' was reached. Others experienced a reduction in contact hours, which allowed for improved preparation and creativity in their educational approach.

4.1.7 Sustainability of the change

This programme of reform is widely seen to be well embedded and likely to be sustained for the foreseeable future. Any reversion back to the 'old education' appears unlikely, particularly given the very strong endorsement from senior university management, who view the reformed programme as a model for good practice within UCL, and positive response from the student body. For most, however, the real key to the sustainability of the reform is the improvement in the quality of students. Almost all faculty members, even those still unconvinced by the nature and scale of the reforms undertaken, commented on this positive outcome of the change process. As one faculty member commented "*we like teaching bright, engaged* *students, no matter whether we agreed [with the change] or not. What would kill it [the changes], though, would be if our student numbers or quality fell".*

The vision and drive for change is clearly very closely associated with the current Head of Department. For some, continuing with such a radical approach across the curriculum may be difficult to maintain if a new Head of Department were to take post. Some concern was expressed that faculty with reservations about the approach may take this opportunity to revert back to the old curriculum within their own courses. This view, however, does not appear to be widespread. Many simply feel that *"we all are too exhausted to make any more changes for quite some time!".*

As a result of the perceived success of the changes in CEGE, the School, with strong support from the university senior management, is planning to roll-out similar educational reforms across all engineering departments. In contrast to the CEGE reforms, change will be driven by senior management at School and university level. It is not yet clear whether this different approach to change will be equally successful; however, important elements of success, including a strong educational vision and senior university management committed to radical change, remain in place.



4.2 Case study 2: School of Engineering, The Hong Kong University of Science and Technology, Hong Kong

Overview: The Hong Kong education system is currently undergoing a radical, government-led change, impacting all secondary and tertiary educational institutions. The School of Engineering at HKUST has taken this opportunity to drive through an additional, and significant, reform to the educational structure and approach of their undergraduate programmes. Planning for the changes commenced within the School of Engineering in 2007 and the first student cohort will be welcomed to the reformed four-year degree programmes in September 2012.

Reasons for selection as a case study: (i) this School-wide educational reform, within a premier research-led institution, was triggered by a 'top-down' mandated change across the sector, (ii) the design and assessment of the reform is informed by a new in-house engineering education innovation centre with a growing international profile, and (iii) evidence gathered on the impact of the changes is likely to inform the use of innovative educational approaches more widely in engineering Schools across Asia.

Who was interviewed: interviews were held with 8 individuals, including those driving the wider educational changes across Hong Kong (the Deputy Secretary of the Hong Kong Education Bureau and the Director of Qualifications of the Hong Kong Institution of Engineers) and stakeholders in the undergraduate programmes in the School of Engineering at HKUST (faculty members, the Associate Dean for Undergraduate Studies and Student Affairs, departmental coordinators for the educational reform, Director of the Center for Engineering Education Innovation (E^2I), an external educational advisor to the School and a recent graduate from the existing programmes).

4.2.1 Context and drivers for change

Context: The Hong Kong University of Science and Technology (HKUST) was established in 1991 and has already built an international reputation for excellence in research, recently ranked as Asia's premier institution in the *QS Asian University Rankings*. Across Hong Kong, HKUST is seen to be a young, dynamic institution that is open to change and encourages new ideas from staff at all levels.

The School of Engineering houses six departments, with a total undergraduate body of around 2000 – about 40% of the University's student population. The existing educational approach is seen to be broadly traditional and 'teacher-centred', with the vast majority of contact time devoted to lecture-based instruction. Since the University's inception, the School of Engineering has established and maintained strong industry partnerships. For many, these links have helped to ensure that the undergraduate education is both responsive to and informed by current practice.

In 2005, the Hong Kong government announced far-reaching changes to secondary and tertiary education, which were designed to "*effectively prepare our next generation to cope with the challenges of the 21st Century and the demands of our rapidly developing knowledge-based society*". The fundamental changes will both impact the city's educational structure (moving from a British to a US system, with secondary education being reduced by 1 year and tertiary education extended by 1 year) and educational approach (broadening the curriculum and a focus on 'whole person development' and 'lifelong learning'). The first cohort of students entered this New Academic Structure (NAS) at senior secondary school level in September 2009, and will move into the higher education system in September 2012. During the 2012/13 academic year, universities will have to accommodate a 'double cohort' of students, with the first intake under the NAS and the final intake under the old educational system entering higher education at the same time. In addition to the NAS, the Hong Kong government is also moving towards an outcomes-based education at undergraduate level. In line with this move, the Hong Kong engineering accreditation agency (*Hong Kong Institution of Engineers*) will require all engineering programmes to adopt an outcomes-based approach starting in 2012.

Drivers: Within the School of Engineering at HKUST, the government-imposed structural changes were seen as a "*rare opportunity for the School to examine critically its educational mission, objectives, and delivery… this was a disruptive rather than incremental change, and rarely would we have such an opportunity*". The School of Engineering has therefore embarked on an additional programme of reform across all of their undergraduate educational programmes. Although triggered by the system-wide reforms, the decision to embark on this 'self-initiated' element of the change was driven by what was described as a "*confluence of events*". Two drivers appear to have been particularly central. Firstly, the School was aware of the growing demand for engineering leaders with a global perspective, and sought to ensure that their graduates were better positioned in this marketplace. Secondly, there were concerns about student recruitment and the decline in popularity of engineering in Hong Kong in favour of subjects such as business – "*after a 10 year decline, we want to make engineering attractive again to our brightest minds*". As a result of these two drivers, the School saw the opportunity to shift from a 'teacher-centred' to a 'learner-centred' paradigm.

4.2.2 The educational vision and changes planned

The School-wide reforms, currently in the planning phases, can be considered in two distinct categories: (i) those changes mandated by the NAS, engineering accreditation requirements and HKUST, and (ii) those self-initiated changes that have been devised and driven through, in parallel, by the School of Engineering. Each is discussed in turn below, with an overview of their implications for education within the School.

Mandatory changes affecting the School of Engineering from 2012. Three sets of changes have been 'imposed' on the School.

Firstly, the system-wide move to the NAS will involve a number of fundamental changes to the city's higher education system: (i) students will enter university a year earlier, with a two-fold increase in student intake numbers in 2012, the 'double cohort' year, (ii) the duration of degree programmes will increase from 3 to 4 years, and (iii) the curriculum will become broader and more flexible, with discipline specialisation occurring in the second-year rather than first-year of study.

Secondly, to coincide with the NAS, HKUST will be introducing some university-wide changes from 2012: (i) all degree courses must incorporate a set of 'common core courses', and (ii) students will be offered a much greater level of flexibility to shape and 'individualise' their educational experience, including the ability to select many options of study (e.g., double major, minor).

Finally, fundamental changes to the engineering accreditation system are planned for gradual implementation from 2012, where all engineering degree programmes will be expected to: (i) be outcomes-based, with the demonstration of a rigorous approach to meeting a selection of the programme's learning outcomes, and (ii) offer a "*better balance between the core engineering education and wider learning*".

Additional reform effort initiated by the School of Engineering. In 2007, in light of the system-wide changes already in the pipeline, a decision was taken by Dean and Heads of Department to undertake a root-and-branch review of the School's educational approach and embark on a more ambitious programme of educational reform. Through this new vision, the School is seeking to produce graduates who can "*operate across traditional boundaries and take on roles that demand not only technical knowledge but a range of other skills, including communication, leadership and management capabilities*". For the majority of those interviewed, these 'self-initiated' reforms are the primary focus of their attention – "*the only mandatory change, really, was to the duration of the education, from 3 to 4 years. What we are doing, though, is much more radical*". The changes driven at the School-level are focused in 3 areas:

- ***Curricular changes.*** Although the nature and extent will vary between departments, changes are planned to the curriculum structure, delivery and assessment. These changes include: (i) reducing the number of required technical courses, (ii) establishing a context for engineering learning with engaging hands-on project experiences, particularly during the early years, (iii) providing students with 'multiple exposures' to critical engineering concepts and ideas at key stages throughout their studies, (iv) increasing the focus on personal and professional skill development, particularly the themes of leadership, innovation and global awareness, and (v) aligning assessment procedures with the new educational approaches.
- ***Non-curricular changes.*** The School is seeking to offer students greater flexibility within the curriculum, such that they have more opportunities to engage in co-curricular and extra-curricular activities. Non-curricular activities will be coordinated by the Associate Dean, and will involve opportunities within engineering, such as industry internships, as well as outside engineering, such as community service projects.
- ***Cross-School educational support and information.*** A key element of the reform involves building cross-School capacity in engineering education, improving both educational delivery (through, for example, encouraging an active faculty dialogue on teaching and leaning, offering instructional development to faculty and supporting 'research informed' teaching practices) and providing formal programmes of student support (through, for example, mentoring programmes and first-year advisory services). Many of these activities are planned to be delivered through the newly established *Center for Engineering Education Innovation* (E^2I).

4.2.3 Achieving change

Within the School of Engineering, planning for the change effort started in earnest in 2007. Early work focused on international benchmarking and consultation. Much of the effort was focused on a review of the engineering curricula at a number of premier US-based engineering Schools and hosting presentations from national and international educational experts. Although the establishment of E^2I in 2010 has subsequently made engineering education scholarship an explicit part of the School's educational reform strategy, the new educational vision and approach was not informed by existing research evidence at the early phase of the reform. As the current Associate Dean comments "*Personally, I was not aware of any of the research… the key mechanism [for designing the reform] is faculty drawing from their own experience and sharing their ideas and outcomes with others*".

Although the change is driven at School-level, authority for the design, planning and implementation of curriculum reforms has been devolved to each individual department, who each will decide how (and the extent to which) any changes are made. As the Associate Dean commented "*…we cannot force change and must respect the autonomy of individual departments and faculty… otherwise we would create a lot of resistance*". The only curricular change that has been mandated at School-level is the requirement to implement an engaging hands-on introductory course at the start of the first year. Otherwise, each department has been asked to design and manage a programme of curricular reform that is tailored to their own needs, but that follows the School's overall educational vision and the need for increased curricular flexibility.

In 2009, curricular change committees were established within all departments, each comprising a cross-section of faculty from all subject areas, who meet every two weeks. Each departmental committee feeds into a central cross-School curriculum change committee, chaired by the Associate Dean, that also meets twice a month. The committees provide a formal mechanism for the exchange of ideas and concerns, as well as reporting on progress in the reform effort, which appears to be highly effective.

The first department to embark on a programme of fundamental curriculum change was the Department of Electronic and Computer Engineering (ECE), in early 2008. This change effort was led by both the Head and Associate Head of Department, who were both well respected and strongly committed to educational reform. The resulting departmental changes involved a fundamental restructuring of the curriculum around four 'layers', each of increasing subject depth. In 2009, the Head of ECE was appointed as Dean of the School, shortly followed by the appointment of the Associate Head of ECE to a new role of Associate Dean for Undergraduate Studies and Student Affairs. Although the reform effort had always enjoyed high levels of support from senior management, to many, these appointments were highly significant and marked a new, and invigorated, direction for the School-wide educational change effort.

Overall, although a clear commitment exists to "*respect departmental autonomy*", the School has employed a number of strategies to encourage and support the educational change effort, as outlined below.

- **Creating a cross-faculty dialogue and engagement in education.** At the heart of the School's change strategy has been the building of a dialogue and sense of community in engineering teaching and learning amongst faculty. This theme was discussed repeatedly by almost all interviewees. Following the city-wide announcement of the NAS, formal and informal channels of dialogue have opened up between universities and across subject areas, which has clearly helped to establish "*a new openness [amongst faculty] to talking and thinking about their teaching*". Within the School, a major focus of the various reform committees is the discussion and exchange of educational ideas, which is supported by external invited speakers and faculty workshops.
- **Freeing up time in the curriculum.** A key barrier to change was the perception amongst many faculty that the "*curriculum was already full and there was no time for anything new*". An explicit early task in the reform, therefore, was to encourage departments to reduce the existing curriculum content to allow space for the development of new courses and student experiences. As the Associate Dean commented "*rather than forcing faculty to make the changes that we would like, we have freed up time in the curriculum and given them much more* flexibility". So, for example, the School has significantly reduced the number of 'technical' courses required in the departmental curriculum. Although some described this process of cutting back the curriculum content as "*a real fight*", it is clear that this process has been successfully completed in most departments.
- **Targeting enthusiasts to pilot innovations.** Particular attention has been focused on the existing champions of change within the departments, on the basis that, once innovations are established, "*further change across the department can grow from there*". The School has therefore sought to empower these enthusiasts, by providing them with the "*time, room and recognition they need*" to implement course-level changes, on a pilot basis, within their departments. Funding is made available at both School and university level for these innovations, and they are championed within the various reform committees.
- **Establishment of a mechanism for continuous educational improvement and support.** In 2010 the *Center for Engineering Education Innovation* (E^2I) was established, to inform and support the School's new educational approach. The centre performs multiple functions, including to: (i) undertake research in engineering education which actively informs practice within the School, (ii) provide faculty with engineering instructional development as well as opportunities for exchange, dialogue and community-building in education, (iii) provide direct support for students in making their educational choices (for example through peer-mentoring schemes), (iv) inform, support and evaluate the current educational reform effort, and (v) act as a 'hub' for engineering education research within Asia. Further details on the role of the centre in the reform effort are given below.

Taking inspiration from a recent ASEE report (Jamieson and Lohmann, 2009), E^2I is seeking to both implement and sustain a world-class educational approach through a "*virtuous cycle of research-informed practice*". Early benchmarking exercises and literature reviews, however, identified two critical limitations of the current evidence base in engineering education – firstly, that it has largely been gathered in 'western' countries and its efficacy on Asian cohorts is largely untested, and, secondly, that the trend in recent engineering education research towards theoretical scholarship provides limited outputs to inform classroom practice. For this reason, the School established E^2I , to act as a bridge between research and practice and establish an Asian hub for research in engineering education. A key focus of activity in this regard has been the development of tools for the assessment of teamwork and lifelong learning skills. In addition to this applied scholarship, the centre is also designed to provide a much more hands-on role in supporting faculty and students.

To date, the centre has been operating for less than a year, but already appears to be making a significant contribution to the change process. Its role and priorities also appear to be responsive to the changing needs of the faculty. As one faculty member commented "*we give them all the problems that the rest of us cannot solve*". Although the centre performs a great many functions, its role in catalysing dialogue and engagement in teaching and learning amongst faculty appears to be critical to the change effort.

4.2.4 Critical factors in successful change

At this stage, 14 months from implementation, it is not possible to assess whether the reforms will be successful.

However, four factors place the School in a particularly strong position during this on-going change process:

- **Strong faculty engagement:** Almost all faculty have accepted and broadly support the need for change, with very little apparent resistance. This acceptance appears to stem from the fact that the NAS changes were externally imposed and have been known about for some time – "*because of the structural need and OBE [outcomes-based education], it has been easier than expected to push forward with the idea*". Faculty engagement appears to have been further supported by the positive outcomes of early pilots and, in particular, the increased motivation seen amongst the participating students – "*even the more reluctant [faculty] see the difference in the students and the higher levels of motivation*". A strong and vocal minority, estimated to be around 20–30% of faculty, are highly committed to the change effort, and are dedicating significant amounts of time to designing and implementing the new curriculum at department level. As one interviewee commented "*every department in the School now has more than just a few people actively involved in the change. There is a real sense of commitment there*". Comments from external observers to the change process also point to significant levels of engagement – "*…they have taken the change to outcomes-based [education] seriously and the level of change is impressive*".

- **Strong support for change from School senior management:** There is a clear sense amongst faculty that the School senior management is actively committed to the new educational vision. Although curriculum reform was acknowledged by a number of interviewees as being a time-consuming process, the clear support from the Dean made them feel that "*this is not wasted effort and it is being recognised*". The cross-School reform committee also provides a formal mechanism to both monitor departmental progress and allow for feedback, ideas and concerns to be communicated with senior management.

- **Cross-faculty exchange and dialogue:** Perhaps the most impressive aspect of the reform effort is the extent to which this process has engaged the faculty with the teaching and learning agenda. For some, the magnitude of the change has acted to bring faculty together to look fundamentally at their educational priorities and approaches – "*as engineers, the scale of the problem has got them interested. If people see change as incremental, the cynics would say "why bother", but this is a significant change and has allowed them to critically examine what they are trying to achieve*". This faculty dialogue has been supported by the recent establishment of E^{2}I, which holds regular seminars and workshops on engineering education. As the Director of E^{2}I commented "*it is so rare for so many people [faculty] to come together to talk about education… There is a really strong level of engagement. This demonstrates that, deep down, people are genuinely interested in teaching and learning. They just needed the opportunity to engage*".

- **On-going educational practice informed by in-house research:** The plans to inform faculty teaching practice by research evidence, gathered in-house or synthesised from the international literature, holds great potential. The research undertaken within E^{2}I is likely to result in some international recognition of the School-wide reform effort, which, in turn, is also likely to have a positive influence on how the reforms are viewed internally. The impact assessments will also support the sustainability of the changes, allowing the School to be responsive to any issues identified and supporting an on-going focus on educational excellence and improvement, even after steady-state is reached.

4.2.5 Challenges in the change process

The most prominent practical challenge of the reform, and one faced by any department/School undergoing a significant educational change, will be the operation of both the 'new' and 'old' curricula during the period of transition - in this case, from 2012 to 2015. The School of Engineering at HKUST, however, will be dealing with a number of additional layers of complexity, as the reform (i) is taking place within an educational system that is also in a state of considerable change, (ii) will be introduced alongside significant changes to the engineering accreditation system, (iii) will be first implemented to a 'double cohort' of students, and (iv) will need to cater for incoming students with very different aptitudes, expectations and aspirations than held by previous generations. Under such circumstances, there is clearly a danger that the School will focus all available efforts on this 3-year transition, rather than considering their longer-term 'steady-state' educational provision beyond 2015.

Early faculty concerns surrounded the reduction of 'core' technical courses and a "*diluting of the engineering science*" in the curriculum. However, many of these fears appear to have been allayed by the results of benchmarking exercises, comparing the balance of "*technical and non-technical content*" in the curriculum at premier US-based engineering Schools, such as Stanford and MIT, with the new educational approach within the School.

A strong theme amongst most interviewees was the levels of uncertainty surrounding the intake to the 2012 programmes – in particular, their academic attainment levels, abilities and expectations. Such concerns are certainly not unique to HKUST, and appear to be echoed across the education system in Hong Kong. Within the School of Engineering at HKUST, faculty concerns centre, in particular, around the levels of mathematical and scientific skills of the new incoming cohorts. The key to overcoming such concerns is clear communication with faculty, which the School appears to be handling well.

There appear to be two strong, but competing, views on the change effort within the School of Engineering. For some (around 20–30%), the Hong Kong-wide structural changes provide a "*not-to-be-missed*" opportunity to rethink and redesign the educational approach. These individuals are actively pressing forward with reform activities. For others, the upcoming city-wide changes will "*already be highly disruptive,* *so further change will be too much to deal with"*. This group only devote the minimum time to the reform activities and "*allow others to carry the burden*". It is a major advantage to the School of Engineering that many of its senior managers appear to be in the former group.

Devolving most reform decisions to the departments has resulted in differing levels of progress towards the reform goals. Some departments, such as ECE, have already made significant changes to their educational approach, while others are still in the planning stages. Such departmental differences appear to be related to the levels of engagement of the Head of Department. As one faculty member commented "*The Dean or Provost is not going to tell individual faculty what to do in terms of classroom activity. This goes down the chain of command. The success will come down to the extent to which the Head of Department can mobilise their faculty*". The departments that have been most successful in the change effort appear most likely to view the changes as department-led rather than School-led. As one faculty member from ECE commented "*although this was School-driven, this is our change and we made it our own*". One considerable challenge for the School will be to ensure that the resulting educational offering, across all departments, is coherent and unified.

4.2.6 Impact of the changes

The School of Engineering is taking a rigorous approach to measuring the impact of the reform, which is informed by the existing international research evidence. Such an approach is highly unusual, particularly for a reform effort at this scale. Impact assessments, the results of which will be shared with individual departments to inform further improvement, will be made on two aspects of the educational change:

- ***The programme-level impact.*** An assessment will be made of the 'value for money' of the reform effort on the educational programmes as a whole. Evidence will be captured from employers (surveys and interviews to be conducted in 2012/13 and 2017/18), students (through entrance and exit surveys and focus groups of cohorts in the new and old curriculum) and faculty (through surveys and interviews in 2012 and 2016). Following early assessments of existing approaches to capturing employer feedback, the School is currently engaged with developing a bespoke set of evaluation tools.
- ***The outcomes-level impact.*** Based on the newly-defined School-wide learning outcomes, an assessment will be made of "*whether the students are learning what we want them to*" at the point of graduation. For example, a snap-shot of student attributes will be taken each year during the final-year capstone project, to assess changes in the personal and professional skills of each graduating cohort. These assessments will be conducted using new instruments, developed in-house, which will focus in particular on teamwork and lifelong learning skills.

It should be noted that impact assessment will be complicated by the system-wide educational change in Hong Kong. As the Director of E^{2}I commented "*. . . the students joining us from 2012 will have been receiving a very different education from the age of 15. It will therefore be very difficult to get 'clean' data on the impact of the changes we are making*". Despite these practical constraints, however, it is clear that the results from these impact studies have the potential to be highly influential. The scholarly approach to the assessment will provide both important data on the overall benefits of educational change at a School-level and valuable insight into the impact of non-traditional educational approaches (such as engaging pedagogies and holistic learning experiences) on large cohorts of Asian students.

4.3 Case study 3: iFoundry, College of Engineering, University of Illinois, US

Overview: iFoundry (The Illinois Foundry for Innovation in Engineering Education) is a grassroots initiative that seeks to nurture, develop and evaluate student-centred courses in pilot form before supporting their wider roll-out into the curriculum. Since its inception in 2007, the educational changes resulting from iFoundry have been focused on liberal arts electives and a cross-School first year experience. The first pilot to operate alongside a core departmental course will be implemented in the 2011/12 academic year.

Reasons for selection as a case study: (i) The iFoundry approach is designed to combat perceived barriers to educational change – principally organisational resistance within departments – by creating a supportive environment outside the formal curriculum for innovation, (ii) iFoundry is working closely with Olin College of Engineering, to see how the creative small-group experiences delivered at this boutique, privately-funded College can be adapted for application to much larger cohorts, and (iii) the drive for change was 'bottom-up', led by a group of faculty.

Who was interviewed: 19 individuals were consulted for this case study investigation. Informal discussions were held with 6 undergraduate students and 4 faculty members, and formal interviews were held with 9 stakeholders to the School's education (including the Dean, Assistant Dean, iFoundry leadership, teaching assistants and faculty members across the School).

4.3.1 Context and drivers for change

Context: The University of Illinois is a high-ranking institution with a strong research reputation in engineering. The College of Engineering[4], comprising 12 departments, has the highest number of National Science Foundation research grants of any institution in the US. The School attracts high-calibre students and is unusual in the US in enrolling them directly into specific engineering disciplines on entry to the university. The School is seen to enjoy a strong reputation for rigor in the education of the engineering sciences, and there is a widespread feeling that this should not be compromised – as the Associate Dean for Undergraduate Education commented "[*the University of] Illinois has done a good job at traditional engineering education – our graduates know their stuff technically. We need not to lose that*". Aside from the establishment of a faculty development programme around 15 year ago, there has been little history of formal School-wide engagement with innovation in engineering education. For example, when the call for proposals for the US Engineering Coalitions was issued in the 1990s, no discussions were held within the School about tendering an application.

The School has a very strong departmental structure, which some describe as "*siloed*". The core curriculum within the departments is seen to be heavily focused towards "*math and physics*", with opportunities for contextualising knowledge and developing students' personal and professional skills typically offered through optional courses, extra-curricular activities or liberal arts electives. Opportunities for innovation or change to the departmental curriculum during the first two years are described as "*very tightly controlled*".

Drivers: iFoundry was established by a small group of faculty who believed that a fundamental shift was necessary in the approach to US engineering education. In particular, iFoundry sought to sustain the international leadership position of the US in engineering through undergraduate education reform, where "*excellence in scientific education and analytical skills is complimented by a broader curriculum that inspires creativity and innovation and includes training in professionalism and leadership traits*". Rather than a programme of change in itself, iFoundry is designed as a catalyst to promote and enable reform, at a course-by-course level, across the School. The iFoundry approach was driven by the need to combat the perceived barriers to educational change in engineering – principally organisational resistance within departments.

4.3.2 The educational vision and changes implemented (to date)

Educational vision. Considerable time and thought have been invested in the educational ideas that underpin iFoundry. Three key themes are most prominent: (i) the incorporation of key critical and creative thinking skills (described as the seven 'missing basics'[5]) into the curriculum, (ii) the development of a strong community of peer support amongst engineering undergraduates from the earliest stage in their studies, and (iii) a strong focus on students' intrinsic motivation for their development as engineers, professionals and life-long learners. iFoundry is also working closely with Olin College of Engineering to see how the innovative educational ideas implemented at this 'boutique' university can be scaled-up for application to larger cohort sizes, with lower resourcing levels.

The iFoundry approach was based around two perceived barriers to educational reform:

- The 'catch-22' problem that an innovation is unlikely to be approved for curricular implementation without evidence of its efficacy in that environment, but such efficacy cannot be demonstrated without the changes first being implemented;

4 For consistency across all case studies, the term 'School' will be used here to describe the College of Engineering.

5 These 'missing basics' are identified as (i) asking questions, (ii) labeling technology and design challenges, (iii) modeling problems qualitatively, (iv) decomposing design problems, (v) gathering data, (vi) visualizing solutions and generating ideas, and (vii) communicating solutions in written and oral form.

- Proposed curricular changes, although often broadly accepted by faculty, are often voted out during the approval process by individuals who are fearful that the changes will adversely affect their current teaching activities or encroach on the curricular time devoted to their specialised subject.

iFoundry is therefore designed to provide a creative and safe environment outside of the formal departmental curriculum where new educational approaches can be piloted, tested and championed by volunteer faculty and students. Using the Dean's signatory authority, all students participating in iFoundry pilots would be credited appropriately within their home department. Such pilots would be designed to run in parallel to an existing, more traditional course, thus requiring positive impacts on student experiences and outcomes to be demonstrated before departmental approval is sought for their full implementation. The intention is that, as the faculty involvement in such pilots increases, their openness to wider curricular change will also increase.

Changes implemented (to date). Outlined below is a summary of educational changes made (up to academic year 2011/12) through iFoundry over the four years since its inception.

- ***Illinois Engineering First-year Experience (iEFX):*** The major iFoundry activity to date has been the development of a School-wide freshman experience, which is designed to build students' intrinsic motivation, within a mutually supportive engineering undergraduate community. The first pilot version of this experience was delivered to 75 volunteer students in the fall of 2009, operating in parallel to the existing mandatory ENG 100 experience that catered for the full cohort of 1500. The second pilot, in the fall of 2010, delivered the course to 300 students. A slightly amended version of the course will be rolled out for the full School-wide cohort in 2011/12, and will replace the existing ENG 100 course.

- ***Liberal arts electives:*** Over the past 2 years, a suite of 'iFoundry' pilot courses have been offered to engineering undergraduates, as liberal arts electives. These include two pilots developed from existing courses offered at Olin College of Engineering – *User-Oriented Collaborative Design/Innovation Design 8 (UOCD/ID8)* and *Foundations of Business and Entrepreneurship*. These 'Olin' pilots are in their second year of implementation. At present, student numbers in these courses are relatively low. For example, a total of 12 students have taken the UOCD/ID8 course over the past 2 years.

- ***Intrinsic Motivation Conversion course.*** During the 2011/12 academic year, a new pilot departmental course will be implemented in the Department of Electrical and Computer Engineering – the ECE 290 core course with multiple pilot *Intrinsic Motivation Conversion* sections. Students are invited to participate in this iFoundry pilot, as an alternative to the existing course, where they will be offered "*a unique classroom experience that relies on their intrinsic motivation*".

4.3.3 Achieving change

iFoundry has its origins in a desire amongst a core group of 6 faculty members to "*just get on with*" curriculum change, rather than continue to discuss and discount various models of reform. The original iFoundry group was formed in 2007 as a grassroots activity. Formal approval for iFoundry was granted by the Dean of the School in 2008. This support was based on the potential of iFoundry to improve: (i) student learning across the School, and (ii) rates of retention during the first two years of study. With the Dean's support also came approval to establish new pilot courses across the School. Since 2008, a School-wide iFoundry committee has been in operation, as a vehicle to champion change, with representatives from every department meeting on a monthly basis.

The early iFoundry activities were focused on "*selling the educational vision within the College and building up expectations that change was coming*", particularly through web-sites and social networking channels. Considerable time has also been devoted to disseminating the iFoundry ideas and model at a national level, including the organisation of two conferences (*Engineer of the Future*). In the Spring of 2009, a memorandum of understanding was signed by all Heads of Department to allow students to enroll in the pilot ENG 100 experience (iEFX).

The iFoundry team described the change strategy as both '*organic*' and '*entrepreneurial*'. In essence, the reform effort is focusing on change at a course-by-course level, with three broad phases envisaged in each case: (i) testing and refining curricular changes through the establishment of pilot courses, (ii) if successful, championing their inclusion in the core departmental curriculum, and (iii) allowing this good practice to permeate out into the departments. As the Dean commented "*it is very difficult to mandate change – it is best to lead by example*". iFoundry seeks to empower students to better understand what they need from their education, and demand it of their departments.

As can be seen from Section 4.3.2, changes have yet to be made to the core curriculum in any department within the School. Activity to date, however, would be seen within iFoundry as critical in both establishing the credibility of the reform effort and validating the concept of operating pilot activities alongside existing courses. As commented by one the iFoundry co-Directors, "*we first piloted an incubator, and now we can incubate pilots*". Planning has started for the first pilot course within a core departmental curriculum, the *IM Conversion,* with an anticipated start-date of September 2011.

iFoundry operates on relatively low resources, with two salaried staff – one full-time Associate Director and one part-time Program Coordinator – and a number of faculty and students engaged on a voluntary basis.

4.3.4 Challenges and success factors

It is clear that the iFoundry programme has enjoyed strong support and the enthusiastic involvement of many highly-committed faculty and students. As iFoundry membership is entirely voluntary, there is little evident hostility amongst faculty towards this reform effort, although there appears to be a view amongst some faculty in the School that they have "*yet to see any real impact from iFoundry*". The incremental and voluntary nature of the reform will inevitably lead to a slower rate of change than that seen across the other case studies included in this report. In this regard, the good levels of support for iFoundry amongst the School senior management – which is currently viewed to be "*central*" to their long-term educational strategy – will be essential if the momentum for this effort is to be maintained.

The majority of activity to date has been led by a relatively small group of faculty members who form the core of the iFoundry management team and, to date, has focused almost exclusively on liberal arts electives and the cross-School freshman experience. As such, it has yet to impact the core curricular activity within the engineering departments or diffuse to wider faculty groups. The coming year appears to be a critical period in the evolution of iFoundry, with three significant challenges being faced:

- In 2011/12, IEFX will be rolled out to the full cohort of 1500 students across the School. This will represent a five-fold increase in student numbers from the 2010/11 pilot and a move away from catering only to volunteer students. Given that the success of the pilot version of this course appeared to be based on the close student/staff interaction and ability to build student community, the School-wide roll-out across such large cohort sizes is likely to be a significant challenge. In addition, for many faculty across the School, the success of this roll-out will be inextricably linked with their perception of iFoundry and the success of this initiative as a whole.

- Internally and externally, iFoundry is strongly associated with the co-founder and current co-director, who retired in January 2011. The vision and educational underpinnings of the initiative are closely aligned with his own educational ideas and many view his passion and commitment to educational change as central to the successful establishment of the initiative. Although this change in leadership will undoubtedly bring some change in the direction of iFoundry, it yet remains unclear what impact it will have on its capacity to catalyse wider curricular change.

- In some senses, the true test of the iFoundry model begins in 2011/12, when the first pilot of a core departmental course will be implemented. As one interviewee commented "*So far, the changes have only been at the margins of the education, not at the core… iFoundry is now on the threshold to a next step after its honeymoon period*". For many, it is too early to determine how this pilot course will be received within the host department, and therefore whether approval will be granted for its implementation into the core curriculum.

4.3.5 Impact of the changes (to date)

Two broad areas of impact of iFoundry were identified by those interviewed for the case study, relating to faculty and students respectively.

With respect to faculty, many of those interviewed for the iFoundry case study talked about its impact on the attitudes towards teaching and learning amongst the faculty involved – "*The biggest achievement of iFoundry has been a shift in culture to one where we think more entrepreneurially with a greater openness to experiment*". From the School perspective, the "*depth and quality of thinking*" is one of the greatest benefits of iFoundry, and it enjoys good levels of support from senior School management. The Dean is very clear about the success criteria for iFoundry. In order to determine whether the initiative has been successful, he would "*want to see 50% of faculty involved with iFoundry and engineering retention rates increased to 80% by the fourth year*".

With respect to students, informal feedback from faculty on the IEFX pilot suggests that student attitudes to the Freshman experience fall into three equally sized groups: (i) those who "*loved*" the experience, which they viewed as "*life changing*" and one which fundamentally shifted their attitudes to their education and future careers, (ii) those who did not view the course as significantly different to the rest of their educational experience, and (iii) those who were very resistant to the course, and disengaged from the non-compulsory and 'community-building' elements at an early stage. Many of those students within the former group, who were highly engaged by the experience, are now actively involved in iFoundry in a voluntary capacity.

The School has also instituted formal mechanisms to capture the student experience. Since 2008/09, it has undertaken a bi-annual 'climate survey' to record the expectations, attitudes and experiences of all its undergraduates. The survey data for 2008/9–2010/11 will provide a 'baseline' from which to track the impact of IEFX from pilot to roll-out phase, and enabling comparison of students on iFoundry courses with their non-participating peers. A formal analysis of the iEFX student experience is also nearing completion.

4.4 Case study 4: Department of Chemical Engineering, University of Queensland, Australia

Overview: The case study describes a department-wide educational reform, where the curriculum was re-designed around a core set of project-based learning experiences that simulated professional engineering practice, termed a 'Project-Centred Curriculum'. Planning for change started in 1996 and the first cohort of students graduated from the reformed 4-year programme in 2001.

Reasons for selection as a case study: (i) the early stages of the change were 'bottom-up', with strong support from a majority of the faculty within the department, (ii) the reform programme is well regarded nationally and internationally and has been used as a benchmark for change at a number of other institutions, (iii) during the 10 years since completion of the reform, the department has encountered, and overcome, a number of challenges in sustaining the quality and impact of the new curriculum.

Who was interviewed: 12 individuals were interviewed, including stakeholders in the educational provision at the time of the reform (including faculty members, a student, the Head of Department, Dean of School and those instigating and managing the change) and stakeholders in the current undergraduate education in the department (including a current student, faculty members, the head of the departmental Teaching and Learning committee and faculty observers from outside both the department and the university). A remote Q&A was also completed by the current Head of Department.

4.4.1 Context and drivers for change

Context. The University of Queensland is a research-led, publically-funded university, founded in 1910. It is a founding member of the Group of Eight coalition of research-led universities in Australia. The Faculty of Engineering, Architecture and Information Technology (referred to here as the School[6]) caters to around 3500 (FTE) engineering undergraduate students, of which 16% are international. Degree courses are four years in duration, with a common School-wide first year and discipline specialisation from the second year of study – at which point, around 15–20% of engineering students select Chemical Engineering.

The Dean of School, who was in post before the reform, had been instrumental in the publication of a pivotal report on the future of Australian engineering education (IEAust, 1996), which recommended radical and widespread changes to existing educational practice across the country. In response to this report, in 1996, the Australian criteria for engineering education accreditation changed to an outcomes-based system, which necessitated significant changes in national approaches to engineering education. In the same year, the newly-appointed Vice Chancellor of the University of Queensland announced plans for widespread change in the educational delivery structure across the university, with a standard unit course size across all departments. For the Department of Chemical Engineering, this 'unitisation' called for a dramatic reduction (by around 50%) in the number of courses per semester and an increase in the size and content of each of these new courses.

Prior to reform, the Department of Chemical Engineering housed around 14 faculty, with around 70 undergraduates in each year group. The department was research-led and enjoyed a very strong national and international reputation for research excellence. Although the department's educational approach was seen to be unremarkable – "*a traditional blend of lectures and tutorials*" – the departmental culture and outlook were seen to be highly distinctive. This theme emerged very strongly from almost every interview conducted. For example, many interviewees pointed to the "*long-standing culture of risk-taking and innovation, with a real spirit of embracing change*". There was a strong collegial feeling amongst the majority of faculty that led to a "*low sense of ownership of individual courses*", and a widespread sense of collective responsibility for the educational programmes. The department's relatively small size clearly played a part in creating this distinctive and mutually respectful atmosphere. Another factor was the strength of leadership – "*the department had a history of spectacular leadership – they were entrepreneurial, ahead of the game…[and]… created a culture that encouraged innovative thinking*". Many of the faculty also had significant industry experience, with a number of recent appointments immediately before the period of reform.

Although not necessarily reflected in the curriculum prior to the reform effort, the department had a history of educational innovation. For example, during the 10 years that preceded the reform, emphasis had been placed on 'resource-based education', where students were encouraged to think and work independently and were able to access a range of different resources for their learning, such as site visits or video presentations. These changes, however, were seen to be only "*partially successful*". Students felt overburdened by the new courses and the resulting educational offering was "*not coordinated and not having the impact we wanted*". Some interviewees described how this experience convinced them that a change effort can only effective when it is "*placed at the heart of the curriculum*". During the decade prior to the reform, the department had also built up a highly effective relationship with the university's Teaching and Educational Development Institute (TEDI). Through this partnership,

6 For consistency across all case studies, 'School' in this case will refer to the Faculty of Engineering, Architecture & Information Technology, and 'department' will refer to the Department of Chemical Engineering as it was in 1996, and School of Chemical Engineering, as it is now.

a significant number of the faculty were 'bought out' from teaching for a semester and given support to redesign a course. Many of the younger faculty had enrolled in a graduate certificate in education through TEDI, and "*came back to the department with their eyes opened and a desire to do things differently*".

Drivers. There does not appear to be a single significant driver for reform, but rather a "*combination of factors and some degree of serendipity*". A significant proportion of faculty held strong personal convictions that a radical change to engineering education was necessary both at national and local levels – "*this group was really agitating for change. There was a real feeling that not only was change necessary, but it would be fun and would put us on the map*". There was also a widespread awareness that two upcoming external policy changes would necessitate a significant reform to the educational structure in the department – the national move to outcomes-based accreditation in engineering and the university-wide 'unitisation' restructuring. For many, these externally-imposed requirements were an opportunity to fundamentally re-examine their whole educational approach. The final factor driving the change was student satisfaction with the existing programmes. During the early to mid 1990s, the department began to receive poor feedback from students and national student satisfaction surveys, which was seen to indicate some deep-rooted problems with the educational approach. The Chemical Engineering programme was seen to be a "*killer degree*" by students, with a curriculum "*packed with technical content and very high student workloads*". Internally collected data on poor student experience was very persuasive in the final decision to change amongst those faculty who had previously been "*on the fence*".

4.4.2 The educational vision and changes implemented

The design of the Project-Centred Curriculum (PCC) responded to a desire to "*develop the full range of engineering graduate attributes needed for professional practice*". The existing curriculum was seen to provide students with a good theoretical framework, but not one which was grounded in professional experience and practice – "*so many academics are now really applied scientists – there was a real need to bring authenticity to the teaching*".

The curriculum was completely re-designed around "*a backbone of project work that is supported by and integrated with all core teaching and learning activities*". As illustrated in Figure 8, around one quarter of the curriculum is devoted to team-based, project-centred courses, which are designed as a "*structured sequence of professional practice simulations*". A further half of the curriculum is dedicated to relatively traditional "*chemical engineering science*" courses, and electives make up the final quarter, providing both breadth and depth. Particular thought and care have been given to the sequence of each course, ensuring the "*cumulative development over four years of both discipline specific and transferable generic graduate attributes*". A team-teaching approach was also adopted, both within the spine of project courses and also across each semester, to ensure the coherent development of the graduate attributes throughout the 4-year curriculum and provide "*improved communications between staff, better collective ownership of the programme overall, and therefore smoother running of individual courses and the overall program*". The curricular inclusion of communication, team work, and independent learning was also supported by flexible and open learning spaces, used for both timetabled classes and informal, unscheduled group discussions. The degree programme also incorporates a number of broader, non-curricular, experiences such as opportunities for undergraduates to tutor group projects in lower years.

4.4.3 Achieving change

The decision to embark on a programme of change was made in 1996, following a strategic departmental planning retreat. The drive for change came from a committed group of around a third of the faculty body, with active support from the Dean of the School. During the early stages, extensive external benchmarking and consultation were conducted, looking at both existing non-traditional approaches to engineering education (such as that witnessed at Aalborg University, Denmark and McMaster University, Canada) and the teaching and learning theories underpinning such innovations. Given that the drive for change initiated from grassroots faculty, this group felt that it was imperative that they were "*well informed and super cautious*" in ensuring that the changes were grounded in established educational research. The group worked closely together over a six month period to identify the fundamental priorities of the department's undergraduate education and develop a new educational structure that emphasised the development of professional engineering skills and attitudes. A very conscious decision was taken to design this new curriculum from the "*top down*", starting with the desired graduate attributes. The idea of the project-centred curriculum (PCC) emerged very quickly, which was seen to be a blend of problem-based learning with professional practice simulations.

Attention was then focused on the remaining faculty within the department and "*getting them on board with the proposals*". The diversity of backgrounds and personalities amongst the original group of faculty champions was clearly a major asset when engaging with the range of different perspectives and concerns regarding the reforms amongst the wider department. For example, two of the key instigators for change were research leaders within the department, and their backing helped to build its credibility amongst research-focused faculty. Throughout this period, there was also "*a lot of open discussions in the department, both formal presentations and informal exchanges, about what we were trying to do*". Soon after, a new Head of Department was appointed from within this group of supporters and he moved quickly to raise expectation for and visibility of the changes, both internally and externally.

The next phase of the change processes was the detailed curriculum design – "*. . . all of the elements were pulled together – the university's unitisation requirements, the outcomes-based accreditation criteria, the outcomes from the benchmarking, a review of the current education – to put together a framework for change*". A 'change committee' was formed amongst the original group of champions, who met regularly during this period. The strong collegiality amongst this group supported

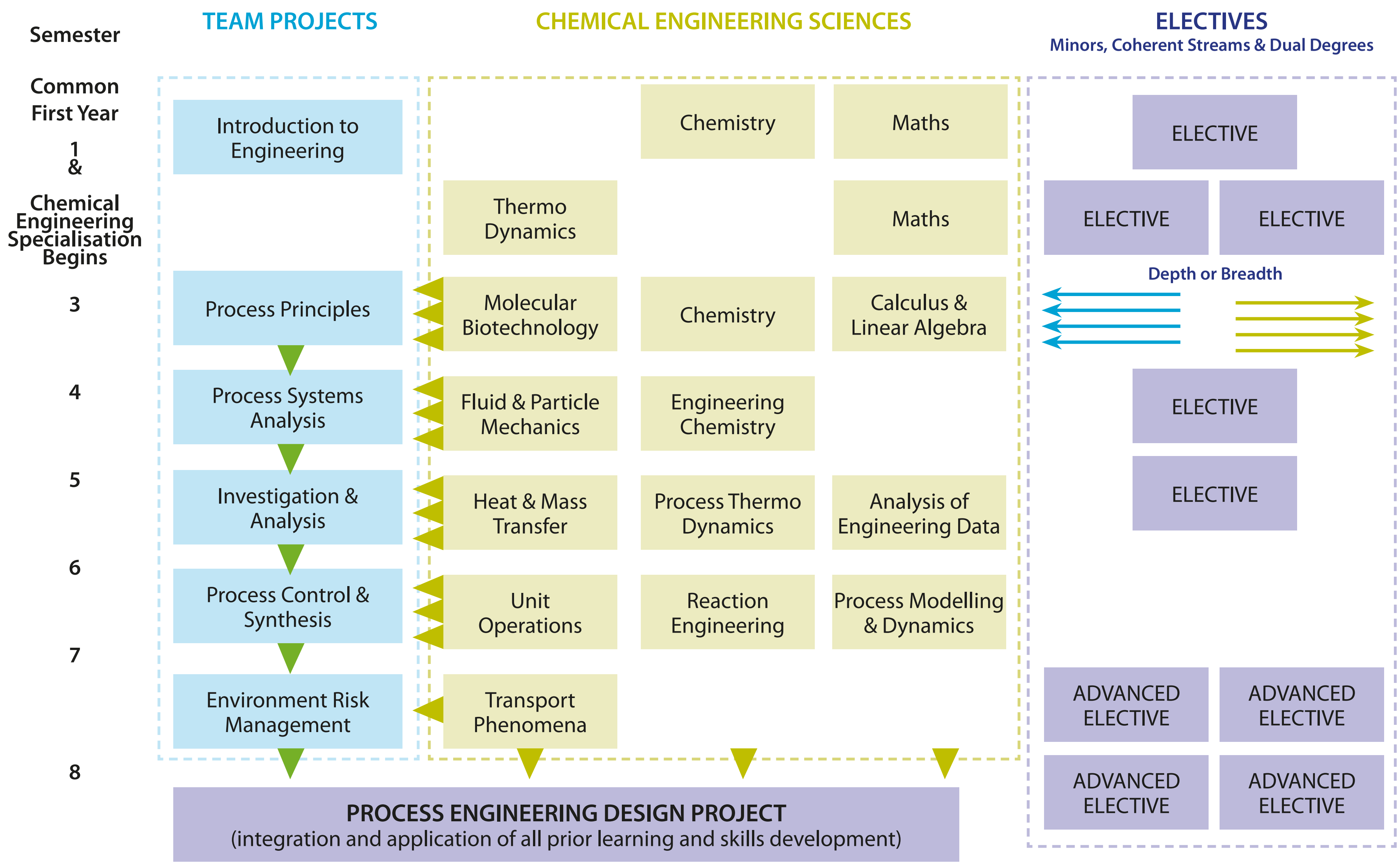


Figure 8. Structure of the Project-Centred Curriculum.

the development of a common vision for the curriculum design – "*we all operated as a team. People had bright ideas and brought them along. You would have been pressed to find a more friendly group who were more passionate about teaching. There was no real resistance*". Two well-regarded individuals took a particular lead in the detailed design and implementation of the PCC reforms – one newly-appointed faculty member whose research focus was the impact assessment of the change programme and one long-standing senior faculty member with a strong research reputation. Although very little additional resource was allocated, the time dedicated to the change effort by these two individuals appears to have been critical.

The new curriculum was implemented between 1998 and 2001, alongside newly-formed faculty teaching teams at the course and semester level. Those faculty who were less supportive of the PCC approach (approximately one third of the department) were allocated to conventionally-taught courses, outside of the project 'spine', and were not pressurised to engage or become significantly involved in the process of curriculum change. All project-centred courses were allocated to those within the PCC change committee. Throughout the implementation of the PCC, consultations were taken from all departmental faculty, students and TEDI. Particular attention was paid to the feedback from the first cohort of students experiencing the new curriculum, and a number of adjustments were made to the curriculum "*on the fly*" during roll-out.

4.4.4 Critical factors in successful change

Overall, four factors appear to have been critical to the success of the change effort, as outlined below.

- ***Shared purpose amongst faculty:*** Perhaps the most significant factor in the success of the reform was the shared commitment to the change amongst a high proportion of the faculty, supported by an existing collegial culture of innovation in the department. This sense of common purpose appears to have been critical in both designing and implementing the PCC. As one interviewee commented "*I have seen other departments handle this so badly, where change was imposed from on high, and the academics just revolted. This was very different. We all felt as though we were in it together*". There also appears to have been a widespread feeling amongst the faculty that "*spending the time to make the change would help my career in the university*". Many interviewees also noted that the reform effort, indeed, was personally beneficial for most of those actively involved – "*There was a strong message from the middle-layers of the university at that time… [that they were] strongly supportive of educational change, and we believed that [the PCC reform] would help our careers… It was naive, perhaps, but it worked out well for almost everyone*".

- ***Strong and well-respected leadership:*** Soon after the decision was made to embark on the reform, a new Head of Department took post, who was appointed internally from amongst the group of original "*agitators for change*". This Head of Department appears to be a critical figure, giving senior support to the effort and ensuring it was given strong visibility across the university. As one interviewee commented "*he took up the champion role from a position of power and influence*". In addition, the two key individuals managing the change process were both well-informed and highly-regarded – "*they are both listened to at high levels, externally and internally*" – and have clearly been influential in maintaining a continued focus on the PCC reforms through the 15 years since its first inception.

- ***Simple and effective educational design.*** The PCC curricular approach is simple and *"driven by good curriculum design principles"*, with faculty teams taking responsibility for creating curricular coherence across semesters as well as within courses. The majority of students appear to understand the curriculum structure and how "*all of the subjects and courses are interconnected*". The logical curriculum design has both helped to ensure clarity and efficacy of approach, internally, but also a highly transferable model, externally. Perhaps for this reason, together with the well disseminated impact evaluation, the PCC has been used as a benchmark for a number of education reforms around the world. Such external recognition has certainly helped to support the on-going focus on the PCC approach internally – "*we have developed a strong reputation, which kept the focus on what we were doing – it is less easy to sweep problems under the carpet when others were watching*".

- ***Carefully-planned impact assessment:*** A well-designed impact evaluation process was undertaken, starting with base-line data collected before the PCC was first implemented (see Section 4.4.6). The evidence from this impact evaluation appears to have played a vital role throughout the reform effort, in a number of respects: (i) to highlight the poor student learning outcomes prior to reform, and thereby support the drive for change, (ii) to demonstrate the early impact of the PCC reforms, maintaining momentum and engagement with the change effort, (iii) identifying problems/issues with the PCC implementation at an early stage, to both ensure remedial action was taken and "*keep us honest about what was really happening*, and (iv) demonstrate the success of the reform effort externally, to both maintain engagement and attract future resources and support to the department.

4.4.5 Challenges in the change process

Unusually, the change effort does not appear to have contended with any significant challenges or "*political agitation against reform*" during the design and planning of the PCC. Although the reform effort was not supported by around 30–40% of faculty, who held reservations about the move away from a traditional educational model, this group were "*not obstructing what we were trying to do*". Around a half of these non-supporting faculty have since left the department. It should be noted that, of those who remain, their opinions of the PCC remain largely unchanged, even 10 years after the new curriculum was implemented. This group still holds concerns about a lack of emphasis on independent study, particularly in the early years, and a lack of rigor in the engineering fundamentals.

The key issue encountered during the implementation of the PCC related to the burden carried by the first cohort of students entering the new curriculum – *"..the group that we experimented on were very patient. We asked a lot of them"*. The detailed curriculum design was managed by semester, but the communication between groups was sometimes inadequate. For this reason, problems encountered during one year of the curriculum were not fed through effectively to the team managing the subsequent years – "*[during the PCC reform meetings] we talked in general terms about the problems associated with individual courses, but others did not know the details and we did not explicitly pass on advice or warnings*". So, for example, although student complaints about excessive workload were soon rectified during one academic year, when the cohort moved into the next year, they encountered identical problems, which was a source of some frustration amongst this student cohort.

Although the reform effort appears to have encountered very few problems during its design and implementation, it has been the sustainability of the change that has provided the greatest challenge. Further detail on these issues is provided in Section 4.4.7.

4.4.6 Impact of the changes

Interview feedback on the impact of the PCC reforms was overwhelmingly positive, by those viewing the changes from both an internal and external perspective. For example, an engineering faculty member from a peer Australian university commented that "*they were real visionaries… Because the department and [the University of Queensland] had a good reputation, they were a good role model for change that worked. Their C-E-Q [score] sky-rocketed after the change, which was a really important factor [in building their national profile]*". Departmental faculty point to a significant shift in the students' outlook and professional skills, following the reforms, along with a dramatic rise in national students prizes awarded and strong, positive feedback from graduate employers.

It is interesting to note that most students do not appear to be aware of the PCC before entering the department. However, soon after they enter, it soon becomes apparent that the educational approach is "*different to the other departments*" and they view the project-centred approach as one where they are more likely to "*retain the underpinning concepts, because we practice it, not just get told it*". The student common room also appears to play a significant role in supporting student learning and building a strong community of peer-support between and across year groups.

The positive impacts of the PCC reforms were illustrated very clearly through the nationwide *Course Experience Questionnaire* (CEQ), which captures feedback each year from all Australian university graduates. Figure 9 presents CEQ data from 1998–2010, comparing graduate feedback for the Chemical Engineering department at the University of Queensland with the national average perceptions of teaching quality (the Good Teaching Scale). The data from 1998–2003[7] indicate a dramatic increase in perceived teaching quality and student satisfaction following the curriculum reform.

The department also undertook 'exit surveys' of those graduating from the programmes before, during and after the changes. These surveys focused on the graduate learning outcomes, and indicated significant benefits from the introduction of the PCC. For example, the proportion of students who felt "*confident of their ability to use skills and knowledge to tackle new, previously unseen situations*" rose from 45% in 1999 to 83% in 2004. In 1999, two thirds of students "*reported a perception that staff did not take an interest in their progress*". By 2004, 80% of the students "*felt part of a group of students and staff committed to learning*".

7 Data from 2000 is not included because of the very low response rate.

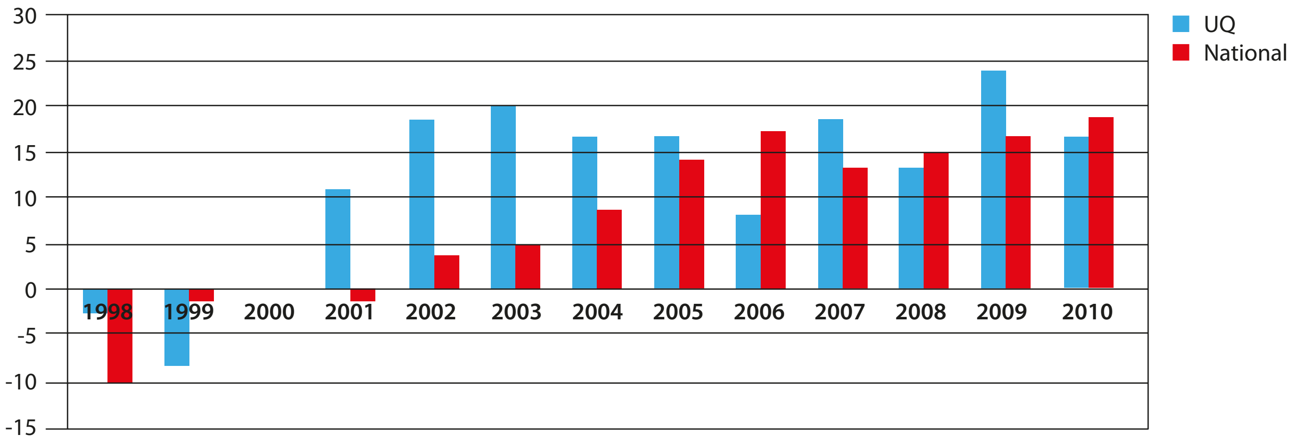


Figure 9. Selected results from the Australian *Course Experience Questionnaire*, 1998–2010, comparing the Good Teaching Scale score for the Department of Chemical Engineering at the University of Queensland with the national average

4.4.7 Sustainability of the change

For 5 years after implementation, the PCC continued to produce exceptional student outcomes and the reform attracted considerable international attention. Many aspects of the new curriculum were, and continue to be, "*hard-wired into the department*". Even for those less engaged faculty who saw the PCC as an overly time-consuming activity, there was a widespread feeling that "*it would take greater effort to change [the PCC curriculum] than to teach it, so there has never been any rumblings to replace the PCC*".

However, in 2006, following a very impressive rise in the department's CEQ rating, this score started to drop, relative to the national average figure (see Figure 9, 2006–08). These declining student satisfaction scores pointed to a "*failure of a number of the project-centred courses to deliver the intended outcomes*". In addition, there was seen to be significant "*drift*" from the original PCC framework and approach, and increasing student concerns about a lack of coherence in the curriculum and poor outcomes in some courses. These problems were caused by a number of factors, both internally and externally imposed, that all combined to undermine the integrity of the department's educational approach, as outlined below.

- ***Changing management structures:*** The most significant factor was the change in the School management structure. The department was merged into a larger School of Engineering in 2001. This move brought a "*loss of identity within a bigger organisation, loss of financial control and a feeling that we had lost control over our destiny*". As another faculty member commented "*the academics suddenly felt far removed from the decision making and lost any ownership over the PCC*". This loss of control and direction led to "a "*reduced focused on our teaching in general, but on the PCC in particular*" across many of the faculty, with minimal priority given to these activities by the discipline leadership at the time.

- ***PCC designers leaving the department:*** Between 2004–2006, many of the key individuals who had inspired and led the PCC reforms moved out of the department or were focused on projects outside the university. The newly-appointed faculty members "*were not part of the change and did not understand what it was all about. They just saw a successful curriculum that just needed to be delivered*". As one leaders of the change commented "*it all happened so quickly*, *we forgot to infect the next generation*".

- ***Changing size and strategic priorities of department:*** There had been a significant increase in the student intake to Chemical Engineering, from 60–80 in the mid-1990s to around 120 by 2008. The larger cohort sizes clearly placed a strain on the project-centred model, just at the point where the PCC was being "*handed over from the people who had developed it to a new generation*". Faculty numbers were also increasing, with new appointees primarily recruited for their research profile and potential, in preparation for the upcoming national research assessment exercise, *Excellence in Research Australia*. The department head at the time was also strongly focused on research outputs, and sent a clear signal to faculty in this direction.

- ***Collection scrutiny and analysis of the impact data "fell by the wayside":*** Impact data relating to the reform was collected until 2008. However, after 2004, close attention was no longer paid to the analysis of this data – "*the new curriculum had been highly successful, people had moved on and the pressure was off*". For some, this meant that the department "*stopped really hearing the feedback from the students*" and were not alerted at an early stage to the problems that were developing.

Following the early success of the PCC, there was some sense that the department had "*taken our eye off the ball*" and not anticipated the coming problems. The dropping of the CEQ scores in 2006 "*helped to focus minds*" back onto the undergraduate programmes.

To date, the department has clearly come a long way to reverse these problems, although, as some acknowledge, "*we have quite a lot more to do*". Student engagement levels have increased significantly, with an improved "*cooperative/collaborative culture within the student body*". This on-going turn-around is reflected in the recent CEQ scores (see Figure 9, 2009–2010) and has been achieved through a number of mechanisms:

- ***Regaining departmental autonomy:*** In 2008, the disciplines of Metallurgy and Chemical Engineering joined to form one department within the larger engineering School. Through this 'demerger', Chemical Engineering was once again allocated with its own budget and a departmental teaching and learning committee. This regained autonomy had a significant impact on the faculty culture, creating "*a feeling […] that Chemical Engineering can move forward with the entrepreneurial spirit that has always characterised the place*" and regaining the collective ownership and pride in their undergraduate education. Significantly, the department was also able to establish its own, independent, teaching and learning committee, and the new chair of this committee has clearly provided a strong sense of direction and commitment to the curriculum.

- ***Strong leadership:*** In 2009, a new Head of Department was appointed, who is strongly committed to undergraduate education generally, and the PCC specifically. From early in this new post, he sent out a clear message to faculty that the PCC curriculum had "*seriously regressed over the proceeding years*" and that remedial action was a strategic priority of the department.

- ***Re-focusing on the original PCC goals:*** After the CEQ data indicated emerging problems, the original developers of the PCC "*went back into the department to explain why and how the new curriculum was designed*". The newly appointed Head of Department also instituted a number of measures, including "*actively assign[ing] my 'best teachers' to the core PCC courses, and ensur[ing] that we resourced those courses properly*". He also focused particular attention to the junior faculty, who "*had no idea about the history of the [PCC] program, nor the basis of its design*". A new series of workshops has been established to discuss the goals, approach and impact of the PCC. Faculty attendance at these workshops is very high.

- ***Improved review and planning approaches:*** A number of departmental procedures have now been amended, including (i) the creation of 5-year plans for teaching teams, to ensure that all less experienced faculty can be linked with a mentor and only those committed faculty members are allocated to the project-centred courses, (ii) the incorporation of student feedback data is now included within the annual review of each faculty member.

The PCC has been an influential benchmark for educational change at a national and international level, and many of the original leaders of the reform programme are now prominent figures in the engineering education community. The rapid improvement in CEQ scores appears to be a key factor in the high regard in which this reform programme is held within the engineering education community.

4.5 Case study 5: Faculty of Engineering and Computing, Coventry University, UK

Overview: The case study describes an on-going adoption of 'Activity-Led Learning' across all five departments in the Faculty of Engineering and Computing in this UK-based university. Planning for the change started in 2007 and the first pilot activity was launched in 2009, followed by a staged School-wide roll-out from 2010.

Reasons for selection as a case study: (i) the vision and energy for change originated from the School senior management, (ii) the changes will be supported by a suite of innovative learning spaces, housed in a new School building currently under construction, designed to support both traditional and active learning approaches, (iii) this School-wide reform is being implemented across a range of engineering and non-engineering disciplines.

Who was interviewed: 19 individuals were consulted for this case study investigation. Focus groups and informal discussions were held with 11 students (in their first and second year of study from across the School) and formal interviews were held with 8 stakeholders to the School's undergraduate education (including the Dean, two Associate Deans, a teaching development fellow, a former Head of Department and faculty from across the School).

4.5.1 Context and drivers for change

Context: Coventry University is a UK-based institution, first established in 1843 as the Coventry College of Design. It was one of 35 former-polytechnics in the UK that were granted university status in 1992 and has a reputation for industry-informed education, particularly in the automotive sector. During the recent shake up of UK higher education funding, Coventry has, almost uniquely, opted to set discipline-specific tuition fees, rather than adopt a standard university-wide fee level. This approach is seen to offer the students both transparency and value-for-money.

The Faculty of Engineering and Computing (referred to here as the School[8]) was formed in 2005, following the merger of the School of Engineering, the School of Mathematics and Information Sciences and the Department of the Built Environment. This new structure brought a new, externally-appointed Dean and four Associate Deans, appointed internally from across a range of disciplines within the School. Overall, the School caters to around 3100 (FTE) undergraduate students, of which 35% are international.

Prior to reform, the educational approach across the School was described as "*a mixed bag, but overall pretty similar to our competitors*". Although there were "*pockets of poor teaching*", there were also examples of excellence and innovation, such as the project-based learning experiences offered within the Motor Sport programmes. During the early 1990s, an attempt was made at grassroots faculty level to encourage a broader adoption of project-based learning into the engineering curriculum. A number of individuals who now hold leadership positions within the School, including one of the Associate Deans, participated in this effort. The failure of this reform effort to take hold was attributed by many to its lack of senior-level support and alignment with the strategic priorities of the School.

Faculty point to their genuine commitment to and close relationship with the students as a particularly strength of the School. Stakeholder interviews indicate that the School caters to a very diverse student cohort, in their demographic profile as well as their academic ability and motivation levels. Providing coherent educational programmes across this wide student spectrum is clearly a challenge, which has been compounded by a recent rise in intake of highly motivated and bright students from Eastern Europe.

Drivers. The change effort was guided by a number of internal and external factors. The senior management of the newly-formed School were seeking to bring "*stability and coherence*" to the educational provision across a range of disciplines. The University's decision to resource a new School-wide building demanded strategic thinking about future learning space requirements and thereby the long-term educational models to be used across all departments. The critical drivers for the change, however, appear to be centred on a need to improve the School's reputation and improve student engagement. In particular, it responded to concerns about: (i) the quality and quantity of the student intake, (ii) low student engagement and retention, particularly during the first 2 years of study, and (iii) graduate employability. At a national level, there were also signals of a likely, and substantial, increase to student tuition fees. In such a climate, where the market for student places would be increasingly competitive, the School viewed a shift towards 'student centred' learning and employability as a means to "*differentiate us in an ever changing competitive market*".

4.5.2 The educational vision and changes implemented

The educational changes across the School have centred on the adoption of Activity-Led Learning (ALL), a learner-centred approach which integrates "*student-led discovery, complex problem solving activities and work-based learning*" where "*involvement in the activity guides the learning*". A conscious decision was taken to develop a new, bespoke, educational approach that both responded to the need for improved students recruitment, retention and employability, but that would also build a national and international reputation for the School as a "*leader and innovator in undergraduate education*".

Much of the early effort has been focused on the establishment of a new, intensive ALL experience for all

8 For the purposes of this case study, 'School' will refer to the Faculty of Engineering and Computing.

students entering the School, during their first year of study – "*this sets the tone, from the outset, for what we expect from the students, building a sense of hard work and creating a work ethic*". In most departments, this early ALL activity has been in the form of a full-time, six week project-based experience. For example, in the Aerospace Systems degree programme, students work through a sequence of scenarios based around an air-crash investigation. Following the implementation of the six-week experiences in 2010, departments are now starting to integrate ALL experiences into later years of the curriculum and will offer a minimum number of ALL-based courses within each year of study by September 2012. The School is also building its strategic links with engineering industry to set an authentic professional context for the ALL learning. It has recently bid for significant external funding to further develop these partnerships, which will be designed to inform the undergraduate experience from the point of application to the programmes, such that "*relevance and vocational educational is driven from the outset*".

In addition to the move towards ALL, the School-wide programme of change involves three new and complimentary elements:

- ***Cross-School student support centre.*** The School has recently established the *Student Experience Enhancement Unit*, to provide peer-support services for students. Around 50 undergraduates are currently employed as 'advocates' within the Unit, and their activities involve: (i) providing front-line services to the School, such as running departmental reception desks, (ii) engaging in educational research, supporting existing faculty-led projects, and (iii) providing one-to-one advocacy services to support individual students to overcome any academic and non-academic problems.

- ***New learning spaces:*** A new cross-School building is due to open in September 2012. The vast majority of the learning spaces will be designed around active learning principles and they will incorporate key features of some of the most well-regarded engineering learning spaces from across the world.

- ***Educational research.*** Integral to the School's educational vision is a stronger international profile in STEM research that would enable it to develop a network of strategic national and international alliances. The School has established an educational research group, chaired by a former Head of Department, to promote a rigorous approach to developing and evaluating educational initiatives – "*We want to be known as a place that takes teaching and learning seriously. In order to move forward with integrity and credibility, we must expose what we are doing to rigorous peer review*".

4.5.3 Achieving change

The decision to undertake a major programme of educational change was taken by the School senior management in 2007, although the content of the new approaches was deliberately left open at this stage. Shortly after, the university allocated funds of around £55m for a new building for the School, to house a significant proportion of its learning spaces, research facilities and faculty offices. As part of the scoping for this new building, the four Associate Deans visited around 15 national and international universities to evaluate some of the most innovative engineering learning spaces from across the world. Many of these spaces were flexible, carefully designed and built to accommodate student-centred engineering learning, through pedagogies such as problem-based learning. Witnessing these different educational approaches, in the context of the new building design, "*forced us [senior management] to think about how we actually would be teaching the students over the next 40–50 years*" and triggered a more fundamental analysis of the School-wide educational approach. The problem-based learning (PBL) approaches witnessed at Aalborg University in Denmark appear to have been particularly influential – "*this was the first line in the sand that gave us a confidence that we could really do something new*". The benchmarking exercise also helped to shape the ultimate educational vision adopted at Coventry – "*they saw examples of PBL in action, and became increasingly convinced that the [School] needed something broader than that… something that took the principles of PBL… [but that was also] reflective of professional practice and helped to prepare students for roles in industry*".

Shortly after returning from these international visits, the Dean and Associate Deans made a series of presentations to the university senior management – including the findings from the benchmarking process and their vision for both the School's educational approach and the learning spaces within the new building. These presentations appear to have been a critical factor in securing strong university support for the educational reform. This support provided the School with the ability to "*quite heavily influence the design of the new building*". In addition, it helped to allay faculty concerns that the reform would not be supported at an institutional level; a concern fuelled by the perception that research was the university's over-riding strategic priority.

In November 2007, an away-day was held with the College senior management and representatives from each department. This meeting both sought to signal the coming educational change, and to "*thrash out*" a more detailed definition of ALL. Over the next 6 months, the School senior management further refined their definition of ALL and started to focus, in particular, on how such an educational approach could be implemented during the first 6 weeks of study, following entry to the degree programme. During this period, the Associate Deans also attended a number of departmental staff meetings, to discuss the rationale of the ALL approach and how it might be implemented into the curriculum.

In July 2008, the School held a compulsory away-day for all faculty, senior management and professional staff to discuss the School's future educational approach. Discussions were focused on the teaching space requirements in the new building and types of activity that might be suitable for implementation in the first 6 weeks. Two months later, the first pilot '6 week experience' was implemented in Mechanical and Automotive Engineering. Student surveys during and after this experience indicated significant improvements in student satisfaction and performance.

In January 2009, the Dean and Associate Deans asked all Heads of Department to implement a compulsory six-week ALL experience at the beginning of the first year of the curriculum in the following academic year. Although the overall structure and approach of this course were prescribed at School level, "*departments were given completely flexibility about how this should be achieved*". To support this change, 30 new Teaching Assistants were employed across the School. These individuals were "*young enthusiastic and very bright*", and appear to have carried some of the burden for implementing this first wave of ALL experiences. In September 2009, all departments implemented their 6-week experience and these models were further refined and developed for the 2010 student intake. Some departments have also taken this opportunity to restructure other elements of the curriculum around ALL. To date, outside the mandatory 6-week experience, levels of ALL implementation vary considerable between departments.

From September 2011, all departments were required to implement a minimum number of course credits that are based on the ALL approach in each year of study – amounting to 25% of course credits in the first and second year and over 40% in the third year. Again, decisions on *how* and *where* such changes are implemented have been left the departments. A further 30 Teaching Assistants are currently being appointed to support these additional changes.

Many view September 2011 as the point when "*ALL will be handed over from the School to the departments*". However, the on-going departmental changes will continue to be supported at the School level by: (i) the former Head of Department of the Built Environment, whose new role is to support change within the departments, develop the School's educational research capacity and to improve its external educational profile, (ii) a cross-School teaching fellow, who is leading the evaluations of the reform programme, (iii) a new Learning, Teaching and Assessment group, to disseminate effective educational practice across the School, and (iv) annual teaching and learning away-days for all faculty and senior management. The new building will open in 2012, and the majority of on-campus courses within the School will be delivered in this space. The School will be hosting a number of national and international engineering education conferences within this space during 2012 and 2013.

4.5.4 Critical factors in successful change

The process of reform across the School is still on-going, and there is clearly some significant variation between departments in the extent and impact of the changes. However, there are clear and strong indicators of successful change. Three factors appear to have been critical:

- A strong commitment amongst faculty to the underlying goals of the reform;
- A very strong commitment and direction to the programme of reform from the School's senior management, and a recognition amongst faculty that this is driven by a genuine commitment to educational improvement;
- A widespread "*feeling of optimism*" in the new educational brand that is seen to place the School in a more secure position for the future.

Each of these elements is discussed in turn below.

Faculty support for the underling reform goals. It is clear that there is overwhelming support amongst faculty for the central goals of the ALL developments – to improve student satisfaction, retention and employability. The vast majority accept that some form of systemic educational change was necessary and that the ALL design was responding to many of the critical issues. Although not all faculty members believe that the ALL model is the most appropriate solution, the strong support for its underlining drivers appears to have softened the resistance to change and played a critical role in unifying most departments behind the reform.

Commitment of School senior management: The change process has been triggered and led by a senior management team who hold a deep-seated and genuine commitment to educational improvement. This team have taken a very hands-on approach to the change, to which they have dedicated very significant amounts of time over the past 5 years – benchmarking, developing the new educational approach, communicating with Heads of Department, faculty and students, coordinating and evaluating the change effort and disseminating the outcomes at a national and international level. The early stages of the process were driven, in particular, by the Associate Deans, whose partnership strengthened their vision and common resolve for radical change – "*this was an extraordinary process. The four of us came together from quite different places, but became quite close. There was a real coming together of minds*". This genuine commitment has clearly been recognised by faculty, and with it an appreciation that there was no "*hidden agenda*" in the change effort, but also that the mandate for change was unlikely to diminish. The Associate Deans were also well-known across the School - each originating from different departments – with a long-standing reputation for "*teaching commitment*". It is also widely understood that both the Dean and Associate Deans see this educational approach as the USP of the School and one which will differentiate it from its competitors as the UK tuition fees increase in 2012. The reform effort also enjoys a strong level of support from university senior management.

The new brand: A widespread feeling of optimism is apparent amongst many of the faculty that "*quality of our teaching is not currently reflected in the league tables*" and the ALL reforms are likely raise the national and international profile of the School, particularly once students start to graduate from the reformed programmes. Even amongst those who hold reservations about the ALL approach, there appears to be a recognition that "*ALL is likely to change our reputation in a positive direction*". In the context of the upcoming increase in UK tuition fees, many see the ALL reforms as placing the School in a much stronger, and safer, position as competition increases for university places. The anticipated impact of the new building was also raised repeatedly by interviewees, and many view the opening of this new space as a potential trigger for the establishment of a stronger educational community across the School and an opportunity for wider profile-raising at a national and international level.

4.5.5 Challenges in the change process

The original vision and energy for the ALL reforms came from the School senior management. The most significant challenge in the change process is translating this engagement into the strategic priorities of each of the departments. As the Dean comments, "*You can strategise all you like, but, in the end, it means nothing if the academics do not believe in it… We always have to keep our focus on the staff who are delivering ALL and the students"*. A critical first stage was "*getting the Head of Department on board*". Although all Heads of Department made a commitment to implement the ALL changes, there was not universal support for the approach. In particular, those subject areas not allied with the engineering disciplines, particularly mathematics, held significant reservation about the universal applicability of the ALL approach – "*teaching maths is fundamentally different from teaching engineering or computer science. Most students chosing maths at degree level do so because they want to learn maths in the same manner that they were taught at [high] school, and therefore do not respond at all well to ALL*". In addition, a number of faculty hold concerns over the responses of international and/or academically weaker students to the ALL environment.

From an early stage, School senior management sent a clear message that the incorporation of ALL into the curriculum was necessary, but that departments would be given freedom over how this was to be achieved. Faculty reactions to this position tended to fall into one of two groups. For some, the challenge and flexibility were seen as "*a real opportunity to do something interesting ourselves*" and has resulted in some significant changes, over and above the mandatory elements. However, others viewed this position as a 'dictat' and were frustrated by the lack of clarity on how such experiences might be designed and implemented in practice. This issue appears to be most acute in non-engineering subjects, particularly mathematics. There also appears to be some discomfort over the fact that the benchmarking exercises were not conducted using direct UK-based competitor universities, but rather with international institutions with very different educational structures, student intake and resourcing levels – "*We don't know what our competitors are doing - the real analysis has not been done. The Associate Deans were looking at what was happening around the world and everything has been based on what they have found. They only visited Australia and the US, and have assumed that the model is transferrable*". Particular concerns were raised by some faculty about the applicability of educational models developed at institutions such as Aalborg University to the School. Internally, messages describing ALL as a "*unique*" approach and one which "*will put Coventry on the map*" appear to be much more effective in galvernising faculty support than those suggesting that ALL derives from effective practice adopted elsewhere.

Across the School, during the early stages of the implementation of the '6-week experiences', faculty concerns centred on the practicalities of the ALL operation – such as the availability of appropriate spaces for ALL delivery, how to integrate late-starting students into the '6-week experience' and how to deliver ALL to large cohort numbers. Although some faculty feel that School senior management were slow to respond to these issues, each appears to have been resolved, with "*compromises made on both sides*".

A number of interviewees commented on an apparent conflict between the institutional priority given to research and the School-level push for educational change. Many would like to see a formalised role for promotion in teaching innovation/excellence – "*80% of our income is from teaching, but so few people are promoted for teaching excellence. This is a major weakness of [the School's] focus on teaching. Things would really change if we saw more promotions. The university is asking everyone to bring in research money, but educational research does not pay*". Perhaps for this reason, much of the burden for implementing the ALL reforms has fallen to a relatively small group of people, estimated to be around 10% of the faculty. Many of these individuals described the experience as "*exhausting*" and there is some apprehension over who, in each department, will be taking on the next wave of ALL implementation in the 2011/12 academic year.

The opening of the new building will clearly be a significant determinant of the overall success of the reform effort. To date, most of the ALL-based courses have been implemented within inappropriate and inflexible spaces. Although new building should rectify these problems, there is some apprehension amongst faculty over the appropriateness of the new teaching spaces and whether, indeed, they will cater to the range of educational delivery modes currently employed across the School.

4.5.6 Impact of the change

A dominant theme in the feedback from both faculty and students was the scale of the educational change undertaken across the School, with representatives from almost every department reporting significant and coherent reform to their first year programs. In the UK context, it is very unusual to find such genuine and widespread change in a School of this size. Given the magnitude of educational change undertaken, what is striking is the positive assessment of the ALL strategy by the faculty. Overall, it is estimated that around 40–50% of faculty are broadly supportive of the widespread implementation of the ALL approach, although there clearly are pockets of much lower levels of support in particular departments. Levels of support appear to be increasing, as "*people start to see the improvement in the students [resulting from the on-going change]*". For those faculty who were less enthusiastic about their experience with ALL, most still saw positive benefits in terms of student engagement, community-building and the development of personal and professional skills – "*…socially, it is brilliant. It gets them working from day one and sets the tone for what we expect from them for the rest of the course*". In general, those departments or semi-autonomous sub-departmental groups whose leadership is strongly supportive of the ALL model report much more positive impacts from the changes implemented to date.

Informal student feedback was also gathered about the newly-implemented first-year ALL courses. The feedback was generally very positive, and almost all students appear to have a coherent understanding of the structure and intended benefits of the learner-centred approach. Most also spoke about high engagement and motivation levels amongst the student body during these activities.

Although it is too soon to determine whether the ALL reforms will be successful, early evaluations of the six-week experiences demonstrate strong student support for the ALL approach. For example, 74% of students who participated in the ALL courses reported that they "*would like to see more of this approach*" across the rest of the curriculum.

4.5.7 Sustainability of the change

Probably the most significant challenge in sustaining the ALL changes will be maintaining the momentum and coherence of the reforms over such a large and diverse School. Departmental faculty and senior management from around 50% of the School now see ALL as "*part of the culture*", where there is "*no going back*" from the significant changes already implemented. For those departments less engaged with the ALL approach, particularly those outside the engineering subjects, it appears likely that only those mandatory changes will be implemented and sustained within the curriculum. There is a strong sense that the "*proof of the pudding*" of the educational changes will come when the new building opens in September 2012 – "*the building will make a huge difference – providing the learning spaces for the ALL experiences, invigorating and unifying the [School], but also raising the profile of what we are trying to achieve*".

The ALL reforms have been implemented during a period of significant change and great uncertainty in UK higher education. In particular, there is an apprehension that the upcoming increase in tuition fees will result in a significant fall in student enrollments within the School in 2012/13 and possibly in subsequent academic years. In line with many universities across the UK, the attention of senior management has been focused on the potential financial impact of the new funding regime. Although this may have caused some delay in the implementation of the educational reforms, the changing market in higher education appears to have strengthened the resolve to ensure that the School is providing a distinctive and high-quality education – "*…[the increase in] tuition fees will be a difficult time and student numbers are going to go down significantly. But we have something that is well-designed and unique and a brand new world-class facility, and are now well placed for the future*".

4.6 Case study 6: Learning Factory, College of Engineering, Penn State University, US

Overview: The Learning Factory, first established in 1995, offers hands-on, professional engineering experiences. The central Learning Factory activity is the 'capstone' design project – a final-year, semester-long team-based activity, where students are tasked with solving real engineering problems, as assigned by industry mentors, and develop their solutions within a purpose-built on-campus workshop space. The capstone design programme is the focus of this case study.

Reasons for selection as a case study: (i) this highly-regarded initiative was established following the receipt of a significant external award, (ii) despite a number of challenges, it has continued to expand over its 16 year history and now caters to around half of the final-year students within the College of Engineering, and (iii) the initiative is driven by a network of effective industry partnerships.

Who was interviewed: 49 individuals were consulted for the case study investigation. Formal interviews were held with 17 individuals, including the Learning Factory founders (the initial Director and senior management supporting the original application for external funding) and current stakeholders to the Learning Factory (including both the current Learning Factory Director and Workshop Manager, Dean of School, Associate Dean for Academic Affairs of School, corporate and alumni relations managers at School and university levels, the university Vice President and Dean for Undergraduate Education, Heads of Department and faculty members within the School and the Director of the Leonhard Centre for the Enhancement of Engineering Education). Informal discussions and focus group sessions were held with a selection of those participating in Fall 2011 Learning Factory projects, including 8 undergraduates, 6 faculty members and 18 industry sponsors.

4.6.1 Context and drivers for change

Context: Penn State is a large public 'land grant' university with a reputation as a "*student-centred research university*". Many interviewees described it as having a "*blue collar*" history with a hands-on approach to both its research and teaching activities. Penn State is seen to be "*less silo-ed than many other universities… [with] … departments that are willing to work together*". The student population is described as being very diverse, both in their academic ability and their career aspirations – *"we take our responsibility to educate students from across the State very seriously, so we take on a huge mix"*.

Within the College of Engineering (referred to here as the School[9]), a long-standing culture of "*valuing engineering education*" is apparent. Indeed, four past presidents of the American Society for Engineering Education (ASEE) have been based within the School, including the current Dean and Associate Dean for Academic Affairs. The ethos has been further reinforced by the Dean, who has sent out a clear message across the School that educational quality is a strategic priority and is one that will be recognised. As one Head of Department commented "*the Dean is key [to the culture of promoting education]. You know he takes teaching seriously. When I talk to him, it is a very balanced discussion between teaching and research… we don't just take teaching for granted in promotions and tenure*". The School also has a long-standing history of working in partnership with engineering industry. For example, during the mid-1980s, the Department of Industrial and Manufacturing Engineering secured funding through the *Ben Franklin Technology Partnership* to establish strategic research partnerships with local manufacturing industries. The partnership created over 50 new projects, providing opportunities for faculty and graduate students to "*work on real-world, practical engineering problems*". During this period, however, despite considerable industry connections in its research activities, the School's undergraduate curriculum had remained predominantly theoretically-based, "*mostly in a lecture recitation format*".

During the 5 years prior to the establishment of the Learning Factory, a number of high-profile engineering education initiatives had been established within the School. In 1990, Penn State was part of a consortium of seven universities that secured one of the first National Science Foundation (NSF) Engineering Education Coalition grants, to establish the *ECSEL Coalition*. The award enhanced the status of engineering education among faculty as an activity that could attract significant and prestigious external funding – "*the ECSEL Coalition broke the ground that education innovations were important and would be supported by the federal government*". In the years following the receipt of this award, the School established two further externally-funded initiatives, the *Leonhard Centre for the Enhancement of Engineering Education* and the *Engineering Design Program*, both seeking to advance knowledge in engineering education and improve the student learning experience.

Drivers: The principal driver for the establishment of the Learning Factory was the availability of significant external funding. In 1993, the *Advanced Research Projects Administration* (ARPA) in partnership with the NSF launched the *Technology Reinvestment Program*, offering funding support for "*manufacturing education and training*". In response to this announcement, the Learning Factory founders formed a coalition with three partner institutions[10], and successfully bid

9 For the purposes of this case study, for consistency across the report, 'School' will refer to the College of Engineering.

10 The *Manufacturing Engineering Education Partnership* (MEEP) members were Penn State University, The University of Puerto Rico, The University of Washington and Sandia National Laboratories.

for around $2.75m. A significant proportion of this funding was matched by the School and industry partners.

Although interviewees for this study were clear that the Learning Factory concept was developed in direct response to the recently-established funding stream, its design and approach were informed by other factors. The *ESCEL Coalition* had successfully worked to introduce design experiences into the early years of the curriculum. However, the later years of study (junior and senior years) remained largely unchanged, and, for some, had become "*rather stale, leaving students unengaged and retention rates low*". By the early 1990s, there was also a growing acknowledgement that a divide existed between the skills, experiences and attitudes held by graduating engineers, and those desired by engineering industry. In this regard, the founding Learning Factory team were particularly influenced by the list of "*desired attributes of an engineer*", produced by Boeing in 1993[11], and sought to provide students with authentic hands-on engineering experiences that "*inject[ed] some life into the curriculum*".

4.6.2 The educational vision and changes implemented

The Learning Factory is described as an "*industry-university partnership to produce world-class engineers by integrating design, manufacturing and business realities into the engineering curriculum*". It seeks to expose students to engineering challenges involving "*a real client and a real problem*", where they work alongside professional engineers and gain hands-on experience developing physical prototypes of their ideas. The Learning Factory offers a dedicated on-campus workshop space, which students can access until 10pm each weekday. Its central activity is the 'capstone' design project, a final-year semester-long team-based activity.

At the beginning of each semester, a network of industry partners are each invited to identify an on-going problem from within their core business, to be offered as a single capstone project for a team of 4–5 students. For each project, the company also provides a mentor to oversee and support the team's activities, and a small donation towards the project and overhead costs. Students, faculty and company sponsors attend a 'kick off' meeting, where all of the projects are presented, and students are given the opportunity to discuss the proposals in more detail with the sponsoring company. Students then vote on their preferred project and are assigned into teams based on their preferences and the disciplinary needs of the project. During their 14-week project, each team member will typically devote 10–15 hours per week to the activity. In addition to the project and prototype development, teams will meet with their faculty supervisors on a weekly basis and will typically arrange face-to-face or remote communications with their company mentor every two weeks. At the close of the semester, student teams present their completed project at a 'showcase' event, to which all industry partners attend.

4.6.3 Achieving change

The catalyst for the establishment of the Learning Factory was securing external funding from ARPA of $2.75m, from 1994–97. This award instantly established a highly-visible profile for the Learning Factory, both internally and nationally. As the Head of the Industrial and Manufacturing Engineering at the time commented, "*this was the biggest grant that my department had ever had – it gave us real credibility*". For some, the funding also played an invaluable role in allowing faculty to "*take a step back*" and reassess the existing undergraduate provision – "*we were already well known. There were not a lot of motivations for change… the money provided incentives for faculty to be involved*".

Some early benchmarking was conducted of existing approaches to hands-on, industry-informed, education. Institutions investigated were all US-based and included the University of New Mexico, Worcester Polytechnic and Harvey Mudd. Although the founding team did not consult pedagogical evidence – "*it just felt right. You don't need research to tell you that*" – they had become interested in the discussions on active learning emerging within the engineering education community. Interactions with their partner institutions[12] was also clearly an energising force during the early stages of the Learning Factory establishment – "*collaborating with those Schools helped everyone, as we were able to see the commonality in engineering education. We saw that the Learning Factory had applicability to everyone*".

Established in 1995, the early development of the Learning Factory was led by two highly-committed and well-regarded champions from two departments: an Assistant Professor from Mechanical Engineering, who provided the "*vision and energy*" for the initiative, and the Head of Industrial and Manufacturing Engineering, who "*kept people's feet to the fire*".

The original ARPA/NSF grant was designed to infuse every year of the curriculum with "*practice-based*" teaching and learning activities. However, because *"there was a lot of faculty resistance to active learning"*, it *"never made in-roads into the curriculum"*. Instead the founders of the Learning Factory focused their attention on the "*big impact classes*", principally the capstone design project. Although some other Learning Factory courses continue (such as the required School-wide *Introduction to Engineering Design* or the optional *Product Realization Minor*), to almost all of those interviewed, the Learning Factory is synonymous with the capstone design programme.

The capstone projects rested on a network of industry partners. The Head of Department of Industrial and Manufacturing Engineering took the lead on developing this network, and it was clearly advantageous that the individual who brokered the initial partnerships was "*someone with real clout who could also really speak for what we were trying to do*". Alongside the network of partners, an Industry Advisory Board was established. Mainly comprising Penn State alumni, this has been a critical driving force behind the direction and energy of the Learning Factory. During the first year of operation, in 1995/96, the Learning Factory offered 6 capstone projects. From this point, and over the next 10 years, the Learning Factory steadily grew within its two host departments of

11 *Desired Attributes of an Engineer*, Boeing (see http://www.boeing.com/educationrelations/attributes.html)

12 After the ARPA/NSF funding ceased in 1998/99, the Learning Factories at the three partner institutions soon folded, with "no vestige" now remaining of the initiative on these campuses.

Mechanical Engineering and Industrial and Manufacturing Engineering. Significant on-going effort was devoted by the Learning Factory supporters and in particular its Director, to securing a "*constant stream of industry projects*".

The Learning Factory is currently managed by a team of three (a part-time Learning Factory Director, a full-time Workshop Manager and a Staff Assistant) together with undergraduate Teaching Assistants. Its operation relies on significant and on-going external funding, amounting to $50–100k each year. Company donations for each team project (currently $3k, increasing to $3.5k where a confidentiality agreement is required) cover many of the basic operational costs, such as events and the team materials and supplies. Additional external funding has been used to develop and maintain the Learning Factory workshop space.

4.6.4 Critical factors in successful change

There are a variety of factors that have contributed to the successful establishment and continuation of the Learning Factory. The School as a whole has a non-typical culture of both prioritising undergraduate education and supporting hands-on approaches to engineering. The current Dean, Associate Dean and a number of Heads of Department have each played critical roles in both championing and protecting the Learning Factory during various stages of its development, as well as securing significant funding for the activity. Indeed, a number of interviewees noted that "*there has been a Dean at all of the Learning Factory events, every year. This sends out a clear message*". The two Learning Factory Directors, both of whom are existing faculty members, have been highly effective; the first establishing the new activity and the second broadening the model across the School.

Perhaps the most striking outcomes of the interviews and observations, however, were the levels of genuine enthusiasm for and commitment to the Learning Factory by all parties involved. Almost all interviewees characterised the initiative as a *"win-win for everyone involved" – students* broaden their engineering capabilities and gain access to potential employers; *faculty* are able to provide engaging and beneficial capstone projects without a significant time and cost commitment; the *School* gains the prestige of hosting an innovative educational endeavor and further cultivates its industry partnerships; *company sponsors* improve their profile amongst Penn State graduates and benefit from fresh new thinking on some of their on-going issues. Not only do all stakeholders feel that they are benefitting from their participation, most see the Learning Factory as the best avenue available to achieve these outcomes.

Underpinning this positive assessment of the Learning Factory are four factors which have been critical to its success:

1. On-going and significant external funding;
2. Its curricular position and approach;
3. The level of student engagement generated;
4. A network of highly committed industry partners.

External funding: The Learning Factory was established following a very significant injection of external funding. With this funding came considerable prestige, a national profile, and a sense that "*we were being watched and we really couldn't fail*". More importantly, the funding ensured that existing School and departmental resources were not compromised by the development of the Learning Factory: the funding enabled it to operate 'in addition to' rather than 'instead of' other School priorities, and it therefore "*did not tread on any toes*". As a "*faculty independent intervention*", it met relatively little active resistance. All interviewees were clear that the Learning Factory could not have been established without the initial award. However, its ongoing operation has been contingent on annual company donations and other donations and prizes, such as the Gordon Prize received in 2006. In order to continue to receive such external resources, the Learning Factory must continue to provide an educational approach that is "*ahead of the game*" and a model valued by US engineering industry. The ability of the Learning Factory to adapt to the changing needs of both students and industry, particularly in recent years, has been a key strength and one that has ensured its continuation.

Curricular position and approach: The Learning Factory's curricular position and approach also minimised active resistance from faculty. It was established shortly before a new accreditation system was implemented across the US, which required engineering programmes to offer a capstone team-based design project and cross-disciplinary experiences. Even amongst those faculty who are not fully supportive of the concept, therefore, "*the Learning Factory is an easy way to check off that [ABET] box"* which would otherwise have had to be created elsewhere in the curriculum. In addition, the Learning Factory holds a relatively autonomous position in the curriculum, as a "*terminal course with very few dependencies*", and therefore does not impact significantly on other teaching activities within the departments. Involvement with Learning Factory is also not "*forced*" on any unwilling faculty, and operates with relatively small faculty numbers – the Fall 2011 activity involves 13 faculty from across 9 departments whereas Spring 2011 involved 18 faculty across 11 departments.

Student engagement and development: The activity is clearly highly engaging and beneficial for the participating students. For many, the Learning Factory has resulted in "*a major change in the quality of our graduates – a quantum jump*". There is a strong sense of student autonomy in driving forward their projects, to which they devote considerable time and thought. This is certainly enhanced by the open-access nature of the workshop spaces, where teams are able to work independently. The increased engagement amongst students participating in the Learning Factory is widely acknowledged by faculty across the School. As one interviewee commented, "*the public displays are impressive and hard to deny. When students go out on interviews, they talk about the Learning Factory. … Even faculty who are not involved can see that students get jobs because of this experience*".

Industry partnerships: Perhaps most importantly, the Learning Factory has established an impressive web of highly-effective company partnerships. For many of the interviewees, this factor has been the key to its on-going success. One particularly striking element of the discussions with the industry partners was their level of genuine enthusiasm for and personal commitment to the Learning Factory. Indeed, many of the most engaged partners are alumni of Penn State. In this respect, the sheer size of the School is a great advantage to the endeavor – company partners gain access to a significant number of students and a large number of Penn State alumni hold posts in major US engineering companies. At the centre of these relationships is the Learning Factory Industry Advisory Board – "*the Industry Advisory Board roll up their sleeves and work shoulder to shoulder with us. These are effective and collegial working relationships… They can see that they make a difference*". Internally, the Learning Factory is also viewed as one element of a larger university-wide strategy to develop and strengthen its industry links. Very considerable amounts of time are spent by the Learning Factory team, corporate and alumni relations managers (at School and university levels), School management, Heads of Department and faculty in securing this engagement.

4.6.5 Challenges in the change process

As noted in the previous section, the Learning Factory did not contend with significant faculty resistance during its start-up phase. For most faculty, the Learning Factory brought clear benefits to the School without any significant compromises. Two faculty concerns were apparent, however.

The first centred on a "*loss of control over the projects*". Potential faculty supervisors were required to pass the responsibility for sourcing their capstone projects to a third party, which brought a significant level of risk – "*what if the project was a dud?*". It took 3–4 years for the Learning Factory team to establish their credibility in selecting the projects and managing the industry relationships – "*they said that they could get the projects, but until they consistently delivered, people were still nervous about getting involved*".

The second faculty concern related to the difficulties in supervising these real-world, complex projects – "*we have had considerable success in bringing people in from industry. But finding faculty is difficult… Many [faculty] don't feel that they can handle it. It is not in their domain. They don't feel like their experience and expertise has prepared them for it*". Supervising Learning Factory projects was also seen to be a highly time consuming activity and not one which many faculty, particularly those on tenure track, could commit to. As a result, securing the required numbers of faculty supervisors for Learning Factory projects was, and continues to be, a challenge.

Perhaps the greatest challenge for sustaining the Learning Factory, however, came in the mid-2000s. Further details on these issues are provided in Section 4.6.7.

4.6.6 Impact of the change

All interview feedback suggested that the impact of the Learning Factory has been overwhelmingly positive. School senior management, participating students, faculty and industry partners all pointed to the significant benefits of the initiative, as summarised below.

- ***Student perspective:*** Since 1995, the number of student participants has steadily increased, with now a half of the 1500 School graduates participating in the Learning Factory each year. Overall, 20% of student participants in Learning Factory projects have been subsequently offered employment by their industry sponsor. Most student participants are aware of the potential of the Learning Factory for securing graduate employment and "*think quite strategically about which corporate sponsor they are selecting*". The students consulted for this study understood the underlying goals of the Learning Factory and its potential benefits for their development as professional engineers.
- ***Industry perspective:*** High levels of enthusiasm were apparent amongst the industry partners, although motives for participation clearly vary. For larger companies, the primary motivator is exposure to bright, motivated and well-educated engineering students. Smaller companies tend to be driven by finding solutions to the projects themselves, and the contributions made by the student teams to their "*back burner*" challenges. The economic downturn appears to have increased interest amongst both communities: where companies are employing fewer graduates, their focus on the quality of selection has increased, and where funding for R&D has decreased, companies are looking for alternative, low-cost ways of developing and improving their operations. The final 'showcase' event is clearly a significant experience for the industry partners, and many commented on the extent to which their mentees had changed through their capstone project, displaying "*maturity, professionalism and ideas that blew us out of the water*". Some also spoke about company cost savings derived from Learning Factory projects running into the hundreds of thousands of dollars.
- ***School and university perspective:*** Both the School and university derived multiple benefits from the Learning Factory, including "*external recognition, contribution to the stature of the university, as well as public interest in what the university is doing*". One particularly beneficial outcome has been the industry partnerships. As a university Corporate Relations Manager commented "*the Learning Factory has changed the relationship of Penn State with some of these engineering companies. Other universities are charging $50k per project for similar programs but the low entry point [of the Learning Factory] means that they can dip their feet in the water to see what the university is all about, and things can grow from there. It is a great way to get corporations on campus*". In 2010, Penn State was placed at the top of a *Wall Street Journal* survey for employable graduates. Many of those interviewed, at a School and university level, credited the Learning Factory as an important factor in the development of this reputation.

4.6.7 Sustainability of the change

During the first 10 years, the Learning Factory continued to expand within its host departments of Mechanical Engineering and Industrial and Manufacturing Engineering and enjoyed enthusiastic support from its industry partners and student participants. However, by the mid-2000s, a number of challenges emerged, threatening the long-term viability of the initiative and forcing a fundamental rethink of its approach. As outlined below, four issues were particularly apparent.

- ***Isolation within the School.*** In the early 2000s, the Department of Industrial and Manufacturing Engineering embarked on a major curriculum reform, integrating inter-disciplinary design experiences into the capstone project. As the existing Learning Factory model did not offer a "*truly interdisciplinary*" experience, the department started to source their capstone projects from elsewhere. By 2005/06, the Learning Factory had developed an "*image of being just a Mechanical Engineering activity*". At this point, there was "*a real danger that the Learning Factory would just become dispersed, with each department having their own version, but no real coherence*".
- ***Difficulties in securing projects:*** Securing the required number of industry projects was becoming increasingly challenging. With each department working independently to establish potential partners for their own capstone projects, "*companies did not know what their point of entry was to the School*". Not only was this a cause of some frustration to industry partners, it meant that only projects that "*fit neatly*" into the boundaries of a specific engineering discipline were likely to be taken forward.
- ***Limited incentives for internal participation:*** It was apparent that non-participating departments within the School felt that the Learning Factory *"was not serving the needs of the School as a whole ... [with] … a sense that it was competing with what the other departments wanted to do"*. The funding model for the initiative was also seen to be a disincentive for other departments to participate. At the time, the company donation received for each project was divided equally between the Learning Factory operation and the team budget for their prototype development. The host departments themselves did not receive a portion of this funding.
- ***The approach was no longer cutting-edge:*** In 1995, the experiences offered by the Learning Factory were almost unique within the US. However, by the mid-2000s, the Learning Factory had "*become stale. It was no longer cutting edge – this was something that many other universities were starting to do*". Many felt that the initiative needed to adapt, and, in particular, start to provide students with meaningful multi-disciplinary and global experiences.

In 2006, in response to these issues, the School made a number of strategic decisions. With a new Director in post, the Learning Factory was re-established as a cross-School activity, serving all departments. This move has clearly been critical – "*[in the past] there was a danger that [the Learning Factory's] success would be dependent on each department's relationship with Mechanical Engineering at any one time. If Mechanical Engineering falls on hard times, the Learning Factory cannot now be 'cut out'*". The newly-appointed Learning Factory Director visited each department in the School and met with key staff, including the Head of Department and undergraduate and project coordinators in each case, to better understand their perceptions of the initiative and the barriers to participation. Following this review, four significant changes were made to the Learning Factory operational model.

- ***School-wide access point for external partners:*** The Learning Factory now takes a School-wide approach to establishing external partnerships, holding collaborative discussions between potential partners and representatives from all departments. As the Learning Factory Director commented, "*You can lose out on a lot of synergies when you are only dealing with one department… Now, we bring people from each department to meetings with potential sponsors. This pulls out a lot more opportunities for multi-disciplinary projects… The more we can do this, the more we can mimic real engineering, where things don't come in boxes*". With these changes, the Learning Factory team "*no longer worry about not getting enough projects. In fact, we now have more projects than student [teams]*".
- ***Bringing new departments into the initiative:*** Significant effort has been devoted to broadening the internal participation. With a new cross-School approach and a greater number of multi-disciplinary projects – "*it is becoming easier and easier to bring new departments into the Learning Factory and make them self-sufficient in terms of company sponsors*".
- ***New funding model:*** The income received for each project was re-distributed. From the basic \$3000 donation, \$1000 is now allocated to the team (for materials, supplies, etc.), \$500 to the Learning Factory operation (for kick off and showcase events) and \$1500 to the host department (for faculty time, labs, etc.). The departments provide the faculty to teach the courses, and the School funds the salary costs for the Learning Factory team (Director and two staff).
- ***Continuous development of the educational goals:*** Greater emphasis has been given to ensuring that the Learning Factory experience reflects the changing needs of both engineering industry and the School as a whole – "*students are changing and the path that they take after they leave us is changing. We have learnt to be really attentive to that*". For example, the experience has now become multi-disciplinary, with the majority of teams now incorporating students from across different departments and some also involving students from outside the School. More recently, the focus has shifted towards integrating cross-cultural experiences. Learning Factory teams bring together students from universities in Korea, Singapore and China, working remotely with students from Penn State. Around 10% of the Penn State students currently participating in the Learning Factory have been involved with such a "*global project*". The ultimate goal is to extend this experience to 80–90% of the student teams.

These changes have clearly re-invigorated the Learning Factory approach and a strong sense of optimism for the future is apparent. It is also acknowledged that the Learning Factory has "*started to pervade the pedagogical experience for capstone design. The connection between faculty and companies had a real impact on people's attitudes, and faculty started to really appreciate what industry was looking for... This was an unexpected outcome. Faculty now hear things personally from industry. This has infected the culture of the School*".

Over the coming five years, the Learning Factory will need to address two particular issues: (i) expanding and upgrading its workshop spaces, which are no longer sufficient for the large number of participating students, and (ii) broaden the pool of faculty supervisors for Learning Factory projects. However, the key to the long-term success of the Learning Factory will be its ability to adapt to the needs of US engineering industry and remain at the cutting-edge of engineering education, thus securing the necessary funding and industry support for its continued operation.

Concluding comments

5.1 Overall observations on educational change in engineering

The study sought to capture the experiences of those who have led, participated in, observed and supported significant programmes of educational change in engineering from across the world, and thereby identify the common features of success and failure. It drew on two primary evidence gathering phases: (i) interviews with 70 international experts and practitioners from 15 countries, and (ii) 6 case study investigations from the UK, US, Australia and Hong Kong, during which a further 117 individuals were consulted. The interview phase of the study provided an overview of current activity and a high level view of the features and strategies associated with successful and unsuccessful change. The case study phase added depth to the picture, looking in detail at the context and strategies for effective change and the impact of each stage in the reform process on each of the major stakeholders.

One area of particular interest was the extent to which geographic differences played a role in the context and strategies for successful change. A number of key differences emerged, mainly connected to the broader climate for supporting educational change at a national level.

All interviewees were asked about the current *climate* for making an educational change within their countries, and the extent to which engineering education reform was encouraged, supported and resourced at both institutional and national levels. Some interesting international differences were apparent in the interviewee responses. In particular, differences were apparent between interviewees from countries, predominantly in the West, that have been engaged in significant national debates on the future of engineering education during the last 15–20 years (such as the US, UK and Australia) and those from countries, mainly in Asia, where the national engagement with engineering education is more recent. These included Hong Kong, Singapore and South Korea, and, outside Asia, Chile.

The former group spoke about growing national support for educational change in engineering and an increasing level of engagement amongst engineering faculty in the need for curricular reform. Many had anticipated that this building momentum would likely trigger widespread and positive educational reform over the coming decade. However, recent government-led cuts to national engineering education support activities as well as to the higher education sector more broadly has led to considerable retrenchment over the past 2–3 years. Many interviewees within the US, UK and Australia spoke with some concern about the potential for positive educational change within the current climate and real uncertainty for what future directions might be taken.

In contrast, many interviewees from the countries that had become more recently engaged at a national level in improving engineering education spoke much more positively about the climate for educational change. Many reported an increase, albeit small, in funding available at a national and institutional level and an increased engagement across the board in the need for change. Interviewees from these countries were also much more likely to cite accreditation, and in particular the move to an outcomes-based system, as a major driver for systemic change. Additional drivers for reform that were particularly noted amongst interviewees from these regions included: (i) increasingly fierce competition between universities for students, (ii) significant demographic shifts amongst incoming students, and (iii) changing knowledge-base and expectations of incoming students from "*the internet generation*".

One issue emerged strongly across almost all interviews and appeared to be independent of geography or institution type: that of the teaching/research balance. Over a half of the individuals consulted reported a perceptible shift in their institutions' priorities towards research outputs, and away from undergraduate education, in the past 5 years. For many, these changes were triggered by an increasing emphasis on national and global university ranking systems. In addition to reducing the institution's focus on educational change, interviewees pointed to two further negative effects of this increased pressure for faculty to hold an unbroken research record. Firstly, the proportion of faculty with significant industry experience has been reducing. These individuals appear to be significantly more likely to support and drive educational change. Secondly, younger faculty are being appointed into a culture that does not reward time and energy invested in educational innovation or change. A number of interviewees who have devoted many years to educational change at their institutions spoke with concern about a "*lack of succession*" to continue the momentum for curriculum reform.

5.2 Common features of programmes of successful change

The study identified a number of common features between programmes of successful, systemic change in engineering education. The features typically associated with success are summarised in Figure 10 and discussed further in the following sections.

5.2.1 Common features of success: context for change

In almost all cases of successful change, there was a clear sense of common purpose amongst faculty, grounded in a widespread acknowledgement that educational reform is unavoidable and/or necessary. This imperative for change is typically triggered by one of the following scenarios:

- The department/School is suffering from a critical problem with their "*position in the marketplace*" – typically declining student intake quality/quantity, increasingly fierce competition or poor graduate employment rates – often resulting in significant pressure to change from university senior management. This enforced need for fundamental change is strongly apparent to faculty, who engage in the collective challenge of the endeavour. Changes triggered under these circumstances appear to be the most likely to produce successful outcomes. The vast majority (around 70–80%) of the change efforts evaluated in this study fall into this category.

	Common features in successful change
The context for change	Most faculty agree that change is unavoidable/necessary, and the primary driver for reform is typically a critical 'market' problem with the existing educational programmes The decision to change is often made in the context of an upcoming institutional/sector-wide restructuring and /or accreditation changes An unusually high proportion of faculty have industry experience and/or have been recently appointed
Leadership and faculty engagement	The Head of Department is fully committed to the reform and is often leading the endeavour University senior management have made their support for the reform both explicit and public Many faculty who are participating in the change process believe that their efforts will be recognised by senior management, although not necessarily rewarded in promotions procedures
Educational design and implementation	The vision for reform is clearly communicated to faculty with an emphasis on the underlying drivers for change. A significant proportion of faculty are committed to the goals of the reform Regardless of the scale of change, the fundamental priorities and approach of the entire degree programme will be re-assessed, such that all changes are a core and integrated element of a coherent curriculum structure A 'unique' educational approach is adopted that seeks to set a benchmark for national/international practice A high proportion of faculty are involved in the curriculum design process A small number of carefully-chosen individuals are tasked with the detailed design, planning and management of the reform, and their time is formally released for this activity No pressure is placed on reluctant faculty to change their preferred delivery style, and a proportion of the curriculum is left largely unchanged where this group can continue to operate Team teaching, or some form of shared teaching responsibility, is adopted across the flag-ship courses
Sustaining change	Long-term impact evaluations are conducted, where outcomes (including early successes) are well disseminated A significant improvement in student intake quality and motivation is apparent following reform Faculty are engaged in some form of on-going educational change/improvement

Figure 10. Common features of successful programmes of educational change, as identified during this study

- In a smaller number of cases (around 10%), the reform is responding to mandatory and externally-imposed changes at a national or university level. Typically, these changes involve a significant university re-structuring or a sector-wide shift, and this opportunity is taken to implement a wider educational change.
- More rarely, in around 5–10% of cases, change occurs within Schools/departments where a collegial culture of innovation and risk-taking already exists. A high proportion of faculty hold a sense of collective responsibility and a shared vision for the undergraduate programmes, as well as a belief that their efforts in improving the curriculum will be recognised at senior levels. Surprisingly, such circumstances appear to be amongst the few where existing innovation or a research background in engineering education is a significant positive influence in the change process.

There appears to be one set of circumstances, almost exclusively US-based, under which successful systemic change is not associated with widespread engagement by faculty on the necessity for change: where the change effort had benefitted from significant external funding. When well supported and managed, such change efforts typically encounter low levels of faculty resistance, because: (i) faculty participation is typically voluntary and their time devoted to the activity is usually 'bought out', (ii) the award of funding brings prestige and external visibility to the change, with an associated pressure for the endeavour to be seen to be successful, and (iii) the activity typically does not draw on significant internal resourcing and therefore does not require cut-backs or compromises to be made elsewhere. The sustainability of such changes, however, is often problematic and usually contingent on an on-going external funding stream and a prominent external profile.

Successful change programmes share a number of other common contextual factors. Firstly, they are much more likely to involve faculty with industry experience and/or newly-hired faculty, often replacing those retiring. Both sets of demographics appear to produce an academic culture that is more open to change and more willing to devote additional time to educational activities. Secondly, the decision to embark on educational reform is frequently made in the context of upcoming changes to the national system of accreditation and/or the recent award for funding of a new building. Thirdly, the leaders of successful changes have often experienced failure in prior attempts to make isolated changes at the course level, from which they concluded that "*change needed to be radical and widespread for it to stick*".

5.5.2 Common features of success: leadership and faculty engagement

Successful change programmes appear to deliver a balance of "*top-down and bottom-up pressures*", where a strong vision and direction from senior management is supported by 'ownership' of the changes by the majority of the faculty. Almost without exception, successful changes are energetically supported by the Head of Department, who invariably is also the leader or co-leader of the change. This individual is typically internally appointed, very highly regarded in both their research and teaching activities, and is seen as an individual who "*walks the talk*". The pivotal role played by the Head of Department in successful change is a major finding of the study. Regardless of the scale of the change (from a small cluster of courses to a School-wide effort), the commitment and leadership of individual Department Heads appears to be a critical factor in its long-term success.

Successful changes are also often supported by the university senior management, from the very early stages of the development of the reform proposals. As a result of this support, university regulations have been waived or moulded to accommodate some of the more unconventional aspects of the reforms. Reflecting engineering departments/Schools in general, successful programmes of change do not appear to be associated with any formal changes to promotions/rewards procedures. However, in many of the cases of successful change, there is a clear understanding that involvement in the reform process (and the resulting withdrawal from other activities) would, at the very least, not count against a faculty member in promotions procedures. In many cases, there is also a strong perception that, although the promotions criteria had not changed, the manner in which they would be applied would be different, and educational innovation and/or participation in a programme of educational change would be valued to a greater extent. This widespread believe amongst faculty is often based on a long-standing trust in the Head of Department and a belief that this individual would "*fight our case*" during promotions procedures.

5.2.3 Common features of success: educational design and implementation

For most of the successful programmes of change included in the study, faculty clearly understand both the drivers for change and the broad strategy to be adopted from an early stage in the process. In particular, the underlying need for educational reform is well-articulated by the change leaders and often supported by evidence. Following these early discussions, a large proportion of faculty are agreed that educational change is necessary and therefore are more likely to support the full change effort.

One clear distinguishing feature of successful changes is the extent to which they have taken a 'step back' and thought fundamentally about what their educational programme is trying to achieve. Such high-level evaluation and re-alignment of the curriculum appears to be a critical success factor, even where the changes only impact a relatively small number of courses. A particularly striking element of the interviews with leaders of successful change is the extent to which they tried to shift faculty thinking towards a more fundamental consideration of educational goals, a shift achieved by encouraging them to look outside of their own specialism to the curriculum as a whole. The radical nature of many of the resulting changes are often seen to engage faculty as a challenge that they can "*get their teeth into, rather than tinkering at the edges of the curriculum*". In addition to its coherent design, the resulting curriculum is also often "*leaner*" with a reduced number of contact hours.

The vast majority of successful change programmes considered in this study have sought to create a unique brand for their educational approach, and one that aspires to set a benchmark for national or international engineering education practice. It is interesting to note that most involve a blend of problem-based learning with professional engineering experiences. Successful change programmes also tend to involve a high proportion, if not all, faculty members in the detailed design of the reformed programmes. Typically, they have managed and sustained change on relatively little additional resource. What appears to be crucial, however, is the formal release of time for a small number of carefully chosen faculty to manage the design and implementation of the reform. Typically, these individuals would have some teaching or administration tasks removed by the Department Head. Changes without release of faculty time tend to result in a significant dilution of the planned reform, on implementation, or an early "*burn-out*" of those tasked with implementing the change.

Despite widespread faculty involvement in curriculum design, almost all successful changes do not force reluctant faculty to change their preferred educational delivery style. In other words, a portion of the curriculum is ring-fenced, typically for lecture-based delivery of traditional content. As one Head of Department commented "*you bring the enthusiasts with you, convert the middle ground, but leave the resisters where they are*". These 'resisters' may be asked to make one change to their activities (teaching a different topic, ensuring that the material delivered feeds coherently into the brief for a future PBL project etc.), but the key components of their day-to-day educational activities will not change.

Finally, more successful change programmes appear to have broken or loosened the direct connection between each faculty member and a particular course, creating a greater sense of shared ownership of the curriculum as a whole. In many cases, this appears to be achieved through a combination of team-teaching and the effects of the whole faculty body having been involved in the curriculum design process.

5.2.4 Common features of success: sustaining change

The principal test of the sustainability of an educational reform appears to be whether it continues beyond a university restructuring or changes to senior management. Reform programmes that appeared to be most resilient in these conditions typically involved at least two of the following features.

1. ***Changes are embedded into the core departmental business:*** Lack of sustainability of a change is often linked to the extent to which it is isolated within the curriculum and reliant on a small number of 'enthusiasts' to deliver the flagship courses. Without a strongly interconnected and coherent curriculum, the importance and impact of the reforms may not be apparent to most faculty, or indeed most students, and they are unlikely to champion for their continuation. Without a wide pool of faculty willing and able to deliver the reformed courses, any staff changes amongst existing course leaders can be catastrophic. Team teaching appears to be a valuable tool in this regard, particularly where the teams are regularly rotated.

2. ***A marked improvement in student engagement is apparent:*** In a high number of cases, the sustainability of change appears to be linked to a significant improvement in student engagement and intake quality resulting from the reform. Even for those faculty who continue to hold reservations about the vision and approach of the reform effort, the improved satisfaction from educating "*bright and motivated*" students brings a wider acceptance of the changes.

3. ***Long-term impact evaluations have been conducted:*** Where conducted, impact evaluations appear to play an important, positive role in supporting change and protecting newly-implemented reforms from the effects of institutional restructures or staff changes. The resulting evidence is often used, to great effect, to both maintain the momentum during the early implementation stages as well as to support the long-term continuation of the reformed curriculum. In practice, however, rigorous impact evaluations are rarely undertaken. One key barrier to their adoption is the lack of commonly accepted success measures and evaluation tools.

4. ***An ongoing focus on educational innovation and/or research is apparent:*** Engagement with a continuous process of educational change in some form, following the formal period of change, is also a common thread amongst those reforms that have been successfully sustained. For some, this took the form of establishing programmes of research in engineering education; for others, it involved a constant cycle of evaluation and improvement to each course. A culture for such continuous improvement appears to be particularly important at the point where new leadership takes post.

5.3 What does NOT appear to be associated with successful change

The interviews and case studies challenged some widely held assumptions about the critical components of successful change. Some key beliefs were not supported by the evidence from this study, as summarised below.

- **Systemic, successful change is not typically triggered by pedagogical evidence:** Very few programmes of successful systemic change considered in this study were informed by the educational research literature before either deciding to make a change or when selecting the desired curricular approach. In other words, pedagogical evidence did not appear to play a significant role in triggering curriculum-wide reform or in shaping its overall educational design. These decisions are almost always made on the basis of "*personal experience in the classroom*" and, in some cases, witnessing a different educational approach elsewhere. The outcomes of this study suggest that evidence of market position are much more critical than pedagogical evidence in triggering systemic change. Indeed, some of the feedback suggested that discussion of pedagogical evidence disengages some faculty from the process; they feel that the original 'test' environment is too different from their own and weakens their sense of ownership of the approach. However, in contrast to curriculum-wide changes, decisions made to embark on reforms at course level, by individual faculty or small teams, are often heavily influenced by the pedagogical evidence.

- **Positive student engagement with the change <u>process</u> does not improve its chances of success:** Although successful programmes of reform invariably produce a curriculum that enhances student engagement, they do appear to be more likely to have benefitted from positive student input during the process of change itself. For example, a number of change programmes have been based on a "*build it and they will come*" model: that if students experience a new, beneficial educational approach in one course, they will demand it elsewhere and force change. In other words change strategies that actively engage students as champions for new approaches to teaching and learning do not appear to have a higher success record than those that do not. In contrast, significant student unhappiness does appear to trigger change in some instances. It should be noted, however, that although positive student engagement does not typically impact the change *process* (e.g., how likely it is to be initiated or sustained), it does appear to improve the quality of resulting educational programmes. So, for example, a robust student consultation process during the design of new curricula is likely to lead to improved learning outcomes for the reformed programme.

- **Existing innovation and/or educational expertise are not critical building blocks for systemic reform:** Existing strong levels of engagement in educational research or a history of educational innovation do not appear to be more common amongst successful curriculum-wide changes. Indeed, in some cases, the presence of a significant minority of existing innovators and/or experts in educational research can create an "*us and them*" division within the faculty during the change process that can have catastrophic impacts. The only instances where existing educational research expertise appeared to be particularly beneficial are where the department is small, collegial and there is a high proportion of faculty supporting change.

- **Good practice does not typically dissipate from existing faculty champions.** The change strategy adopted in many programmes of reform is to identify existing innovators, empower them to implement change in their courses, and then encourage this 'good practice' to dissipate out to the rest of the curriculum. Such models appear to have good early success within the target courses, but, ultimately, these innovations do not dissipate and are not themselves sustained over the long-term, unless supported by strong leadership and an overarching strategic vision. All of the evidence from the study points to change only being successfully implemented when a high proportion of the faculty are engaged in the educational design/approach and sustained only when the changes are part of a critical examination and re-shaping of the whole curriculum.

5.4 Common features of unsuccessful change

The study points to 3 stages where in the change process where failure is most likely to occur:

- ***The pre-planning stage:*** following the presentation of the new educational vision for change to the faculty, before any detailed planning for the reform has taken place. On learning about the broad plans for reform, a high proportion of the faculty "*revolt*", and the change effort is abandoned. The key concerns of faculty typically centre on one or more of the following: (i) that the changes will result in a "*dumbing down*" of the curriculum, (ii) that they, fundamentally, do not agree with the underlying need for change, (iii) they do not believe that the proposed changes align with the strategic priorities of the university, and/or (iv) that they are fearful that the changes will adversely affect their day-to-day jobs. Failure at this early stage tends to be associated with a lack of effective communication across the faculty about the planned changes (and, in particular, *why* change is necessary and what benefits it will bring to the individual faculty member) and/or the low credibility of the individual/s proposing the changes.

- ***The pre-roll out stage:*** at a late stage in the planning process or early stage in the roll-out of the reform. Where there is over-reliance on a small number of individuals, poor planning and/or insufficient resourcing for the reform-effort, those charged with leading the change "*burn-out*" and are unable to deliver the planned reforms. In some cases, the change effort is abandoned soon after, but, more frequently, the momentum behind the reforms slows down, resulting in a much diluted change that is not well supported and therefore proves to be unsustainable.

- ***The post-implementation stage:*** in the 5–10 years following the implementation of the reform. Following roll-out, change efforts appear not to be sustained for a number of reasons: (i) the allocated resources are insufficient to sustain the reforms in their steady-state, (ii) the new courses/programmes are over-reliant on one or two individuals, who either "*burn out*" or move on, (iii) strong student or faculty dissatisfaction, and (iv) most commonly, senior management do not continue to monitor the impact and operation of the new curriculum and faculty start to revert, unnoticed, to the previous curriculum within their courses.

5.5 Recommendations

5.5.1 For the engineering education community

The study has highlighted a number of barriers and facilitators of systemic educational change in engineering Schools and departments across the world. On the basis of the study findings, the prevalence and success-rate of curriculum reform would be significantly improved by:

1. The development of a set of simple tools to measure effective teaching and learning in engineering. Such tools would serve two very important purposes: (i) to support the process of promotion and reward of faculty based on their educational contribution, and (ii) to provide an accepted template by which departments/School could monitor the impact of curriculum reforms without the need to develop their own bespoke models.

2. The ready availability of evidence on the impact of educational reform on programme performance. Given that the majority of successful reform efforts are triggered by a critical, largely market-driven, problem, evidence of the long-term impact of change endeavours in improving their market position would be of great benefit to others considering change. Such evidence could be in the form of a longitudinal study of a successful reform effort from a well-regarded institution, charting the impact of the change on factors such as recruitment, retention and employability, and comparing these with competitor institutions.

3. Funding to support educational change should be allocated, where possible, to whole departments with the explicit involvement of the Department Head, rather than to individuals or groups. Receipt of funding should also be contingent on a long-term impact analysis.

5.5.2 For engineering Schools and departments

The study has identified a number of strategies and features associated with successful and sustainable change. On the basis of these findings, a number of specific recommendations have been made to support engineering Schools and departments wishing to embark on widespread educational change. These are summarised in Figure 11.

PREPARATION
Collect evidence: gather quantitative evidence of the performance of your programme, as compared to competitor institutions, with a focus on key areas of concern to your current or future market position.
Engage the Head of Department: devote as much energy as possible to ensuring that the Department Head is actively supporting, and preferably leading, the change. If their support is limited, be aware that your chances of long-term success will be severely diminished.
Consult senior university management: open informal discussions with university management about plans for change. Identify potential conflicts and gauge levels of support.
PLANNING
Communicate need for reform to department-wide faculty: focus on the critical need for change, supported by the evidence gathered, and the potential impact of reform on faculty day-to-day activities. Avoid specifying details of *what* the change should look like. Underline university support for change, if this is in place.
Faculty-wide curriculum design: engage most, if not all, faculty in a department-wide educational design process. Encourage them to think outside their discipline, identify the fundamental educational priorities and design a coherent curriculum and where all new elements are carefully interlinked with existing courses. The new educational approach should be distinct and something that will put your institution 'on the map'. At least one portion of the curriculum should remain unchanged.
Consult external perspectives: ensure that some external voices are heard. Possibilities include an Industrial Advisory Board with real 'teeth', sending faculty to visit peer institutions that have implemented positive changes and/or appointing an educational/industrial advisor. Such activities are particularly important where there has been little recent faculty turn-over and/or few faculty have industry experience.
Appoint a management team and release their time: carefully select a management team of 2–3 individuals who are well-respected and understand the detailed operation of the undergraduate programmes. Formally release a portion of their time to devote to detailed planning and implementation.
Establish impact evaluation: select a method by which you can collect impact data throughout and beyond the change process and collect 'base-line' data relating to the period prior to reform.
IMPLEMENTATION
Select implementers of reform: those implementing the first pilot phases of reform should not necessarily be the 'usual suspects' of existing innovators in the department. Do not attempt to force highly reluctant faculty to deliver any of the new courses at any point in the process.
Loosen direct link between faculty and individual courses: where possible, establish team teaching for all new courses, with regular rotation of faculty. Provide a dedicated forum for teams to meet.
Maintain momentum: ensure regular dialogue between faculty and change leaders. Ensure that the change is publicly noted as a priority by senior departmental and university management. Disseminate early successes internally and externally.
SUSTAINING THE CHANGE
Closely monitor impact data: continue to collect and monitor impact data for a sustained period. Continue to flag results, positive and negative, internally. Disseminate successes externally.
Make new faculty aware of the reform: ensure that all new faculty are fully aware of <u>why</u> the reforms were undertaken and the impact of the changes made. Assign new faculty to experienced teaching teams.
Establish an on-going focus on education: ensure that the new curriculum is not stagnant. Engage in continuous development that keeps the curriculum at the cutting edge. Establish activities that are likely to engage a range of faculty. These will vary by context, but might include an engineering education research group, membership of international communities and/or faculty development workshops.
Be aware of potential issues: during university re-structuring and/or changes to senior management place particular emphasis on above 3 tasks and communicate the drivers for and impact of the reforms to all faculty.

Figure 11. Recommendations for departments/School wishing to embark on systemic change, based on the study outcomes

Appendix A

List of those interviewed

Listed below are the 70 individuals consulted during the second phase of this study, as outlined in Chapter 3. It should be noted that the additional 53 interviewees consulted for the case study investigations (as presented in Chapter 4) are not included in this list.

Esat Alpay	Senior Lecturer in Engineering Education, Faculty of Engineering, Imperial College London
Helen Atkinson	Head of Mechanics of Materials, Department of Engineering, University of Leicester
Angela van Barneveld	PhD Candidate, Learning Design and Technology, Purdue University
Maura Borrego	Associate Professor, Department of Engineering Education, Virginia Tech
Mike Bramhall	Head of Teaching, Learning and Assessment, Faculty of Arts, Computing Engineering and Sciences, Sheffield Hallam University
Lori Breslow	Director, Teaching and Learning Laboratory, MIT
Doris Brodeur	Lecturer and Director of Learning Assessment, Department of Aeronautics and Astronautics, MIT
James Busfield	Reader in Materials, School of Engineering and Materials Science, Queen Mary, University of London
Ian Cameron	Senior Fellow, Australian Learning & Teaching Council and Professor, Chemical Engineering, University of Queensland
Duncan Campbell	Alternate Head of School, School of Engineering Systems, Queensland University of Technology
Malcolm Carr-West	Engineering Education Consultant, MCW Consulting
Jianzhong Cha	Chair on Cooperation between Higher Engineering Education and Industries, Department of Mechanical Engineering, Beijing Jiaotong University
Albert Chow	Director of Qualifications, Hong Kong Institution of Engineers
Robin Clark	Head of Learning and Teaching Research, CLIPP, Aston University
Ed Crawley	Ford Professor of Engineering, Professor of Aeronautics and Astronautics and Engineering Systems and Director, Bernard M. Gordon – MIT Engineering Leadership Program, MIT
Caroline Crosthwaite	Director of Studies and Associate Dean, Faculty of Engineering, Physical Sciences & Architecture, University of Queensland
John Dickens	Former-Director, Higher Education Academy Engineering Subject Centre and Engineering Centre for Excellence in Teaching and Learning, University of Loughborough
Kristina Edström	School of Education and Communication in Engineering Sciences, KTH Royal Institute of Technology
Ng Eng Hong	Director, School of Mechanical and Aeronautical Engineering, Singapore Polytechnic
Charles Engel	Visiting Professor, University of Manchester
Marco Federighi	Faculty Tutor and Sub-Dean of Engineering Sciences, University College London
Norman Fortenberry	Executive Director, American Society for Engineering Education
Duncan Fraser	Professor, Department of Chemical Engineering, University of Cape Town
Gary Gladding	Professor and Associate Head for Undergraduate Programs, Department of Physics, University of Illinois
Svante Gunnarsson	Professor, Division of Automatic Control, Department of Electrical Engineering, Linköping University
David Goldberg	Change consultant, ThreeJoy Associates and former- Jerry S. Dobrovolny Distinguished Professor in Entrepreneurial Engineering and co-director, iFoundry, University of Illinois
David Good	Lecturer, Department of Social and Developmental Psychology, University of Cambridge
Peter Goodhew	Director of the UK Centre for Materials Education, Department of Engineering, University of Liverpool
Roger Hadgraft	Director, Engineering Learning Unit, Melbourne School of Engineering
Charles Henderson	Associate Professor, Mallinson Institute for Science Education, Western Michigan University
Ron Hugo	Head, Department of Mechanical & Manufacturing Engineering, University of Calgary
Brent Jesiek	Assistant Professor of Engineering Education, Department of Engineering Education, Purdue University
Margaret Jollands	Discipline Head, Civil, Environmental & Chemical Engineering, RMIT University
Ashraf Kassim	Vice-Dean, Faculty of Engineering, National University of Singapore

Edmond Ko	Director, Center for Engineering Education Innovation and Adjunct Professor, Chemical Engineering, Hong Kong University of Science and Technology
Anette Kolmos	Professor in Engineering Education and PBL and Chairholder, UNESCO Chair in Problem Based Learning in Engineering Education, Aalborg University
Russell Korte	Assistant Professor, Department of Human Resource Education, University of Illinois
Peter Kutnick	Professor, Chair of Psychology and Education, Associate Dean of Research, Faculty of Education, University of Hong Kong
Helene Leong	Deputy Director, Department of Educational Development, Singapore Polytechnic
Fiona Lamb	Associate Director, Engineering Centre for Excellence in Teaching and Learning, Loughborough University
Tom Litzinger	Director, Leonhard Center for the Enhancement of Engineering Education, Penn State University
Johan Malmqvist	Professor, Department of Product and Production Development, Chalmers University of Technology
Fred Maillardet	Chairman, Engineering Professors Council and Former Dean of the Faculty of Science and Engineering, University of Brighton
Fiona Martland	Director, Engineering Professors Council
Ivan Moore	Director, Centre for Promoting Learner Autonomy, Sheffield Hallam University
Angelica Natera	Senior Program Development Officer, LASPAU, Harvard University
David Nethercot	Head, Department of Civil and Environmental Engineering and Deputy Principal (Teaching), Engineering Faculty, Imperial College London
Karoli Njau	Nelson Mandela Institute of Science and Technology, Tanzania
Carolyn Percifield	Director of Strategic Planning and Assessment, College of Engineering, Purdue University
John Pritchard	Assistant Director (Institutions), The Higher Education Academy (UK)
David Radcliffe	Kamyar Haghighi Head, Department Of Engineering Education, Purdue University
Teri Reed-Rhoads	Assistant Dean of Engineering for Undergraduate Education, Associate Professor of Engineering Education, Purdue University
Carl Reidsema	Associate Professor and Director of Teaching and Learning, School of Mechanical and Mining Engineering, University of Queensland
Tom Ridgman	Director, External Education, Institute for Manufacturing, University of Cambridge
Jose Manuel Robles	Dean, Faculty of Engineering, Universidad Del Desarrollo
Lim Seh Chun	Deputy Dean, Faculty of Engineering, National University of Singapore
Richard Shearman	Deputy CEO, Engineering Council UK
Cheah Sin Moh	Deputy Director, School of Chemical and Life Sciences, Singapore Polytechnic
Karl Smith	Cooperative Learning Professor of Engineering Education, School of Engineering Education (Part Time), Purdue University and Morse-Alumni Distinguished Teaching Professor, University of Minnesota
Deborah Sneddon	Deputy Director of Formation. Engineering Council UK
Diane Soderholm	Education Director, Gordon-MIT Engineering Leadership Program, MIT
Simon Steiner	Discipline Lead – Engineering, Higher Education Academy
Johannes Strobel	Assistant Professor, Engineering Education & Educational Technology, Purdue University
Pee Suat Hoon	Director, Department of Educational Development, Singapore Polytechnic
Bland Tomkinson	University Adviser on Pedagogic Development, University of Manchester
Uranchimeg Tudevdagva	Professor, Power Engineering School, Mongolian University of Science and Technology
Faith Wainwright	Dean, Arup University, Arup
Jae Youn	Director, Global Education Center for Engineers and Professor, Materials Science and Engineering, Seoul National University
Ng Weng Lam	Director, School of Electronics and Electrical Engineering, Singapore Polytechnic
Khairiyah Mohd Yusof	Associate Professor/Head of Department of Chemical Engineering, Universiti Teknologi Malaysia

Appendix B

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