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Business in Engineering Education: Issues, Identities, Hybrids, and Limits

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Business in Engineering Education: Issues, Identities, Hybrids, and Limits

Mike Murphy, Pat O'Donnell and John Jameson

Abstract: This chapter explores how engineering students are broadened in their education through the teaching of non-engineering subjects, such as business subjects, in order to develop critical thinking skills and self-knowledge of what it means to be an engineer. The goal of the chapter is to provide a commentary on the level of interaction, from design of courses to design of curricula, between business faculty and engineering faculty, and the results of that interaction. This chapter sets out to (i) explore whether there appears to be a place in engineering education curricula for reflective critique of assumptions related to business thinking, and why; (ii) discover what kinds of business issues are reflected in engineering education curricula, and for what purpose; (iii) explore the degree of business hybridization in engineering degree programs; (iv) ask who teaches business issues within engineering education? To this end a taxonomy of engineering enlightenment is proposed, and this is used to discuss evidence of broadening with engineering curricula. The approach adopted is to describe all relevant engineering degree programs in Ireland, based on their publicly available program information; examine the accreditation reports for these same programs; and then survey deans from colleges or schools of business to examine whether the business college/school is involved in the education of engineering students in the institution or university. If yes, how the business college or relevant business faculty are engaged in the design of engineering curricula. In order to enable a comparative discussion, the chapter will focus on Irish engineering programs that seek accreditation from Engineers Ireland for professional engineering. A number of hybrid engineering programs of study are also explored, and their apparent strengths discussed, including hybridity limits.

Keywords: Veblen, Mitcham, engineering education, business, accreditation, self-reflection, taxonomy of engineering enlightenment, curriculum broadening

Introduction

> "…by the time we understand the pattern we are in, the definition we are making for ourselves, it's too late to break out of the box. …Yet the definition we have made of ourselves is ourselves. To break out of it, we must make a new self. But how can the self make a new self when the selflessness which it is, is the only substance from which the new self can be made?"
>
> Robert Penn Warren, All the King's Men

Not long after the Great War, the American economist and sociologist Thorstein Veblen argued for a technocracy in which the welfare of humanity would be entrusted to the control of the engineers. "The material welfare of the community is unreservedly bound up with the due working of this industrial system, and therefore with its unreserved control by the engineers, who alone are competent to manage it," he stated, and thereby it was solely the engineers who could optimize and maximize its output (Veblen 1921). But less than a hundred years later, the philosopher of technology Carl Mitcham cried *stop* and argued that "neither engineers nor politicians deliberate seriously on the role of engineering in transforming our world. Instead, they limit themselves to celebratory clichés about economic benefit, national defense, and innovation". (Mitcham 2014) The greatest engineering challenge, according to Mitcham, is to cultivate "deeper and more critical thinking … about the ways engineering is transforming how and why we live". This is also in marked contrast to Meijknecht and Drongelen who explored the spirituality of engineering and who described the societal value of engineering as follows: "From early times, they have answered the needs of people not by building sentences, but by constructing machines or water managing systems, organizing storage and transport of goods and food supplies, offering cities the conditions to grow and make life good and comfortable" (2004). The realization that, as a class, engineers are indeed transforming the world is a profound and sobering thought, and Mitcham's challenge that engineers must deliberate seriously on their role in this transformation deserves to be explored. This is compounded by his more-than-implicit criticism that the way the world is transforming and evolving is not desirable, to say nothing of optimal, that engineers have contributed through their activities of designing and constructing new structures, processes, and products to a quality of life, indeed to a way of living, that isn't what it could be; that it is engineers as a class, who are responsible for over-promising the benefits of technology and under-delivering on a better society.

The world today, in the first quarter of the 21st century, is a complex system of interconnected and competing economies, political systems and cultures. It is a system which by and large has evolved to focus on unconstrained growth, and for which Mitcham despairs that "relatively few engineers, when invited to reflect on their professions, can do much more than echo libertarian appeals to the need for unfettered innovation to fuel endless growth." In terms of future models, Richard Heinberg of the Post Carbon Institute argues that "economic growth as we have known it is over and done with" (2011). He argues that going forward, only relative growth is possible, that "the global economy is playing a zero-sum game, with an ever shrinking pot to be divided among the winners". The absence of growth, he argues, does not necessarily imply a lack of improvement, and that within a non-growing economy the emphasis must shift from more consumption to better quality of life. Whether unfettered growth or no growth, both agree that a shift is required to examine and improve the society in which we live. But where the engineer sits in this society is becoming increasingly uncomfortable. Meijknecht and van Drongelen (2004) note that for engineers "the days of comfortable autonomy are over and done with. Engineers can no longer hide in the realms of science and technology and focus solely on the development of new technologies. As mediators between science and the world they live in, engineers have the task of finding ways to sustain and develop life in a balanced and adequate way by controlling and explaining the complicated processes in nature and human existence."

Engineering education concerns itself with useful learning: that engineering students are educated to do something with their learning – generally to solve problems through the development of technology, and thereby improve the world. "The question asked by engineers is not *what is the idea behind it? What is the concept? Where does this all stem from?* but *does it work?"* (Meijknecht and Drongelen 2004). Useful learning embodies the duality of engineering education. According to Debora Johnson "Whenever you build something physical, you also build something social. Engineers are making society," she says. "They are making technology, but technology is society." (quoted in Kaplan-Leiserson). This is important in order to ensure that engineers are not just cogs on a wheel, but that they also are capable of thinking about the wheel that they are designing.

But Carl Mitcham's argument in a nutshell is that there is too much *use* and not enough *learning* in the typical undergraduate engineering program. Accepting the larger societal point about the need to examine how and why engineering is transforming how we live, and the individual point that the engineer should seek self-knowledge through reflection and self-examination, this chapter sets out to discover how engineering education broadens the engineering student. In particular, what kinds of non-engineering courses are reflected in engineering education curricula? We explore whether there is evidence that sufficient space has been allocated within engineering curricula for self-reflection and critical thinking on the ways engineering is transforming how and why we live. We do this by examining the elements of engineering education that can be considered as providing evidence of a broadening agenda, in particular an education that asks engineering students to examine societal impacts, innovation and entrepreneurship.

Taxonomy of Engineering Enlightenment

Let us begin with the working assumption that engineers, as a profession, believe that they are more than merely expert cogs on a wheel. They also comprehend the wheel and the purpose of the wheel. There is a secondary question as to whether *all* engineers must have this broader understanding, but since in this chapter we are discussing the development of professional engineers, the simple answer for our purposes is *yes.* "Engineering programs like to promote innovation in product creation, and to some extent in pedagogy, yet almost never in critical thinking about what it means to be an engineer. How about engineers who can think holistically and critically about their own role in making our world and assist their non-engineering fellow citizens as well in thinking that goes beyond superficial promotions of the new?" (Mitcham 2014) We now propose a taxonomy and a framework by which engineering programs may be examined in order to gain insight into the degree to which programs attempt to develop this broader and critical understanding within their students.

A taxonomy or classification is proposed by which engineering programs may be examined.

Level 4:	Engineers transform the world and they can reflect on what it means for all of us
Level 3:	Engineers transform the world and they can justify it rationally and contextually
Level 2:	Engineers transform the world and they can communicate it clearly
Level 1:	Engineers transform the world because they can

Figure 1: Taxonomy of Engineering Enlightenment

This taxonomy is adapted from Mitcham's arguments to engineering schools about how humanities courses are justified in their ability to support the enlightenment of engineers, and is shown in the framework below.

4	Intrinsic Value justification	Social Sciences courses enable critical self-reflection on the meaning of life in a progressively engineered world
3	Enhanced Instrumental justification	Social Sciences courses can locate engineering projects within their broader social context
2	Instrumental justification	Social Sciences courses can improve the communications skills of engineers
1	No justification	Education is through the core disciplines of engineering

Table 1: Framework to justify non-Engineering Courses within Engineering Curricula (after Mitcham)

The set of non-engineering programs has been broadened to include social sciences, which Mitcham accepts. We note in passing that the fields of the Humanities, Social Sciences and Liberal Arts are generally invoked when proposing either broadening or hybrid engineering programs. By using this framework, the purpose behind a broadening course can be examined. Engineering programs can also be examined to see whether there is constructive alignment between the goal or aims of the program and the evidence of success in terms of the level (1 through 4) to which each program appears to be operating. We also note in passing here that in a commentary on Mitcham's article, Christensen (2015) observes that it is the dominant core-periphery distinction in engineering education that ensures that attempts to broaden the curriculum are doomed to fail. We explore this point later in discussing findings. Since the majority of engineering programs undergo accreditation of one form or another, then examining the process of accreditation and the evidence resulting from accreditation visits provides one means to apply the above taxonomy. A second is through the review of available information for each program.

Scope and Methodology

The scope of this review is all engineering programs in Ireland accredited for the educational level of professional engineer. To complete this review, every such program in Irish universities and institutes of technology (IoT) was identified. Publicly available information for each program was reviewed. Next, the accreditation reports of every program for the last ten years were studied. This was followed by semi-structured interviews with deans and heads of business colleges, which were conducted to examine the degree to which engineering programs sought non-engineering support to teach subjects within the engineering curricula. Finally, some relevant selected data from the Irish Survey of Student Engagement (ISSE) is presented, and we discuss a small number of hybrid engineering degree programs. By examining every relevant Irish engineering program, this review can comment on whether there is evidence of systemic approaches to a broadening agenda, whether there is evidence of institutional approaches, or evidence of broadening approaches only at the program level.

Background

The majority of engineering graduates are educated to work in engineering companies within engineering roles. It is self-evident to say that is why they are educated as engineers. Doctors are not educated to work as teachers, nor lawyers educated to work as clergy, so it is hardly surprising that institutions set out to educate engineers to work as engineers. Consequently the majority of engineering students are educated in accredited engineering programs with the clear expectation that as graduates they will be capable of functioning as engineers in the workforce. That many engineering graduates move smoothly over their careers from technical roles to non-technical roles (often management roles) is a positive statement on their educational and professional competence.

The debate continues within the engineering educational sector regarding the effectiveness of many programs in preparing graduating students for the changed world in which they will practice their profession. Goold (2015, p.215) asserts that "neither the engineering profession nor the educational system supporting it has kept pace with the changing nature of the "knowledge-intensive society and the global marketplace" [Degerstedt et al, 2008]. There is an evident need to build an expanded educational curriculum which better reflects the reality of the engineer's role in society.

For many undergraduate engineering programs the technical and mathematical sciences on which engineering courses are built often do not explain the landscape of practice (Trevelyan, 2013). As a consequence "many of the engineering students who make it to graduation enter the workforce ill-equipped for the complex interactions, across many disciplines, of real-world engineered systems" (Wulf & Fisher, 2002). The failure to adequately respond to such criticisms is undermining the educational experience of many student engineers and impacting on their career prospects beyond graduation. Many engineers are compelled to retrain, indeed to reinvent themselves, a relatively few years after graduation in order to remain relevant and employable, and to obtain the broader perspective required in a more mature professional. While all professionals have to do this to a degree, it is a bigger and more difficult leap for engineers, particularly when their undergraduate education has given them too narrow a foundation.

The nature of many undergraduate engineering programs is that they are narrow and technical with little time or curriculum space for non-core content. The typical undergraduate engineering program is characterised by the "dominance of the applied engineering sciences at the expense of tacit knowledge, political, social and economic perspectives and ability to achieve practical results through other people is noticeably lacking in the students' engineering education [Goold, 2015]. If engineering is to play its required role in society then engineering needs to redefine its identity more broadly and engineering education needs to respond with a more comprehensive curriculum.

Part of the under provision can be explained by a lack of curriculum space on many undergraduate engineering programs. A greater problem however involves the lack of acceptance of the legitimacy of non-core engineering content by staff and students within engineering departments. Too many undergraduate engineering programs have failed to respond to the changing role of the engineer in society.

The failure to respond positively to the need to broaden the engineering curriculum has drawn the attention of many commentators. A warning has been sounded in some quarters suggesting that technical engineering skills may becoming commoditised and as a consequence the graduating engineer would not be ideally suited to meet the requirements of the future labour market, which requires a degree of convergence between technological and non-technological skills (Grimson et al., 2008). The call for an engineering education response is growing. Some authors have predicted that if engineers do not accept hybrid engineering degree programs they will be constrained to purely technical work activities. (Grimson et al., 2008)

There is a need to reconceptualise undergraduate engineering education to reflect the actual practice of engineering in its broader socially defined context. Trevelyan argues that "while technical expertise distinguishes engineers as an occupational group, socio-technical factors shape the landscape of practice." (Trevelyan, J., 2014). Trevelyan further states that 'building a deep understanding of engineering practice into the curriculum has the potential to greatly strengthen engineering education (Trevelyan, J. (2010)). It has been suggested that an engineer is a 'composite' person in that it is not only science and technology that is of concern but also ethics, law, the impact on society and environmental aspects being just a few of many legitimate concerns that impact on how an engineer functions. (Grimson et al., 2008) Without a broadened educational experience many graduating engineers may struggle in terms of their employability despite their technical proficiency. These concerns represent a challenge for those responsible for the education and early development of tomorrow's engineer. (Grimson et al., 2008)

In reviewing the work of an engineer Trevelyan (2014) concluded that a typical "engineering project is specified by client requirements, standards, regulations, social needs and environmental constraints and it has a project life cycle" - characteristics beyond the narrow domain of many undergraduate engineering programs. He concluded that "Engineers need to know it all: the engineering enterprise, explicit knowledge, procedural knowledge, implicit knowledge, tacit knowledge, contextual knowledge, engineering knowledge and technical knowledge in the workplace" (Trevelyan, 2014)

Within industry, many companies describe the ideal graduate employee in terms of the T-shaped graduate, with an appropriate balance between the breadth and depth of the "T". The vertical stroke represents the depth. In the case of the engineer the depth is, appropriately, in the core science and technology. The horizontal stroke represents the breadth - the range of multidisciplinary knowledge and skills that provides an individual with the perspective and skillset necessary to critically and holistically assess their contribution, and crucially "to collaborate across disciplines" (Brown, 2017). It appears that engineering academics overwhelmingly believe that their institutions compete with others almost exclusively on the technical excellence of their graduates. The feedback from industry on the actual graduates they employ, however, is that the main deficiencies lie in the breadth: "The reality is that when people come out of school, they're often I-shaped" (Brown, 2017).
When the voice of industry, with its ultimately commercial focus, is added to the general commentary, one is led to the conclusion that the modern world requires a more rounded engineer, with the rounding provided by multidisciplinary studies and personal development.

Authors such as Williams [5] and Heywood (2008) have argued that the engineering profession has lost its identity, and that in the long run engineers will have to face up to a long term convergence between technological and liberal arts education. The prediction is that if engineers do not adopt a hybrid educational model they will be consigned to purely technical work activities. The emergence of new hybrid career professionals requires new engineering educational responses in which student engineers are exposed to the influence of other communities and other disciplines in order to acquire an understanding of how people from other disciplines think. The engineer's identity crisis referred to by Williams (2003) has been reinterpreted by Dias (2008) as involving three distinct crises to which the discipline and its education provision needs to respond. A crisis of the nature of engineering knowledge – a theory or practice; a crisis of engineering role – that of a scientist or a manager; and a crisis of values underpinning engineering decision making. The changing identity of the engineer and their role in society is in urgent need of clarification to guide educators in their provision of a more comprehensive curriculum and experiential learning formation.

In chapter 17 of this text, authors Juhl and Buch (2017) make a simple but compelling case for a more integrated approach to engineering education. They state that "As a nexus, engineering-business combines 'engineering' – the domain that develops technologies by 'applying' science and mathematics to practical problems, and 'business' – the domain that translates technology into market applications. (Juhl and Buch (2017). The objective is to make engineering education more reflective of engineering practice, to become more reflective, holistic, and innovative in which "engineering is seen as a socio-technical endeavour that fuses technical disciplines and social science disciplines into a mix that fosters 'a hybrid imagination' (Jamison et al. 2011). The composite nature of the work of an engineer requires a composite educational model in which a broad set of multi-disciplinary skills, knowledge and competencies are developed. There is some evidence that such multi-disciplinary approaches are being developed through hybrid undergraduate engineering programs.

Throughout the academic literature and in a number of academic institutions engineering program design is starting to reflect this broader perspective with the expansion of course choice and the development of innovative hybrid programs which combine engineering with non- engineering disciplines. In some insistences such as Carnegie Mellon University and Johns Hopkins University in the US students are offered dual degrees which combine engineering and business in an integrated educational experience which reflects the practice of engineering.

Carnegie Mellon's dual program offers a "new integrated engineering and business program culminating in a Bachelor of Science degree in engineering and a master's degree in business administration", while Johns Hopkins's dual degree program will offer School of Engineering students a unique opportunity to bridge gaps between the engineering and business fields prompting the Dean of the Carey Business School to comment that "the nexus between engineering design and business application has never been stronger in today's economy. Breakthroughs and discoveries need to be economically viable to have a lasting impact on the world," (Ferrari, 2016).

The Dean of the Johns Hopkins Engineering School added "Johns Hopkins engineering students are extremely entrepreneurial in the way they approach solving problems. They are eager to turn their innovations into products that can have an impact on people's lives, and the partnership with the Carey School will provide them with the business skills they need to do this." (Schlesinger, 2016)

Another exemplar of an innovative hybrid response to undergraduate engineering education is offered by the work at Technical University of Denmark (DTU). The engineering program "Design & Innovation" was built around the necessary competences needed for engineers to practice design in professional settings. The composition was based on three equally important basic knowledge- and skills- components: 'reflective technological engineering competences', 'creative, synthesis oriented competence', and 'innovative socio-technical competences'. The program was innovative in so far as it gives equal importance to the social and the technical sciences (Jorgensen et al. 2011, p. 11), making social science an accredited part of the core curriculum of an engineering program. From the outset the designers of the DTU program viewed the domains of engineering and business as hang(ing) together in mutually constitutive and intricate ways" (Juhl and Buch (2017, P20) where engineers solve problems by developing products, artefacts and technological solutions while business translates these technology solutions into market applications.

Former Harvard President Derek Bok has been quoted as stating that many students graduate college today "without being able to write well enough to satisfy their employers … reason clearly or perform competently in analysing complex, non-technical problems" (Arum and Roksa). While it is not clear whether the exclusion of technical problem solving represents a general absolution for engineering programs and the students and faculty engaged with them, it hints at the larger problem of the disengagement of faculty from active learning by their (engineering) students and whether the heart of this issue rests with the faculty and administrators and not with the students. Mitcham critiques engineering education by arguing that engineering programs like to promote innovation in product creation, and to some extent in pedagogy, yet almost never in critical thinking about what it means to be an engineer. These are the questions on which this chapter attempts to shed some light.

Review of Professional Engineering Programs in Ireland

This section summarises findings and makes some broad conclusions regarding broadening of the engineering curriculum and the involvement of non-engineering experts, in particular from social sciences, in the education of engineering students. The section concludes with a re-formulation / re-statement of the problem that we are seeking to address.

A high level review of the content of accredited professional engineering programs currently offered by Universities and Institutes of Technology (IoT) in Ireland was carried out. The objective of the review was to examine the extent and nature of non-core disciplinary modules or elements of modules contained in these programs. The review was limited to readily accessible information, either online or in print format, the extent and level of detail of which varied greatly from one institution to another. As a result some broadening material may have been missed, and some material may have been included that has little broadening effect. But the numerical results provide a reasonable indication of the actual extent of inclusion of broadening material in engineering programs in Ireland, and a qualitative analysis of the program descriptions provides additional evidence of this. It also provides an illustration of the perceived importance of broadening the education of engineers in Ireland within the engineering academic community. It should also be noted that there is anecdotal evidence that individual lecturers often require project work from engineering students within core disciplinary modules with contextual and societal emphasis.

Definition of Broadening Content

Broadening is defined here as modules and content from non-engineering disciplines that are intended to develop a different way of thinking and relating to society and the world. In this sense we take a more inclusive view than humanities alone, but also include the social sciences, the arts and subjects generally related to the commercial, civic or creative domains such as business, management, finance, law, psychology, ethics, citizenship, art, culture, philosophy, spirituality, etc. It does not include content that is part of the traditional core science, mathematics or technology-based content of engineering programs, including related areas such as design, manufacturing, quality, systems engineering, etc. Thus for our purposes, project management is not a broadening subject, whereas other aspects of management can be. Generic and transferable skills such as communication, team-working and critical thinking are deemed to be broadening. Work placements and modules involving service learning / community engagement are deemed to develop generic skills. Semester-long or year-long projects are frequently designed to develop generic as well as technical skills. These were counted as broadening wherever the module title included words such as "integrating", "team" or "capstone", or where the module description states that the project contributes to the development of generic skills as a learning objective. Sustainability and environmental impact are deemed to be core engineering concerns and not necessarily broadening in themselves, although they do give rise to a heightened focus on societal impact. Biological and bioengineering modules and topics are considered core to Biomedical Engineering programs and are therefore not broadening. Electives were not counted as broadening, even when the options included broadening content. However, data were gathered on the number of programs with elective lists that included broadening modules. Optional non-credit bearing modules were ignored. The analysis therefore looks at more than what might be described as "core" business content. This is justified on the basis that the economic, social and cultural aspects of modern life are so interrelated that it is necessary to consider them in the round. Professional and ethical behaviour, generic skills such as critical thinking and communication, and knowledge of the humanities are just as relevant to a business education as to an engineering one. For the purposes of the analysis, broadening content is therefore divided into four categories:

1. Core business content: management, finance, law, marketing, economics etc.
2. Professional and ethical development: including the regulatory environment.
3. Generic Skills: Critical thinking, team working, personal effectiveness etc. Work placement and service learning modules were considered significant contributors in this regard.
4. Other broadening non-technical disciplines: arts, humanities, etc.

Programs Included in the Study

There are 94 in-scope professional accredited engineering programs in Ireland, as listed on the Engineers Ireland website (accessed 30 June 2016). 70 of these are at Level 8 (Honours Bachelor Degree) on the Irish National Framework of Qualifications (NFQ), which is equivalent to Level 6 of the European Quality Framework (EQF), or First Cycle of the Bologna Framework. The remaining 24 are at Level 9 (Master Degree) of the Irish NFQ, equivalent to Level 7 of the EQF or Second Cycle of the Bologna Framework.

Of the 94 in-scope programs, 69 are offered for the 2016/2017 academic year, according to institution websites (accessed September to November 2016). The quality of information available online and in other literature in respect of these programs varies greatly. In some instances, nothing more than a short description is provided. In the majority of cases, a listing of module titles, which provides the most basic evidence of broadening content, is provided. In a small minority of cases, full details of learning outcomes and syllabus content are accessible. The breakdown of the 69 programs offered in 2016/2017 between levels and sectors, and the types of information available for them is displayed in Table 2.

	Number of programs offered			Modules listed	Full syllabus provided
	Level 8	Level 9	Total		
University	29	12	41	39	6
IoT	21	7	28	25	7
Total	50	19	69	64	13

Table 2: Number of accredited programs offered in 2016/17

For 5 of the 69 programs, only broad descriptions are provided to the public - module titles are not listed. As noted above, module titles provide the most basic evidence of broadening content, so the 5 programs for which they are not available are excluded from the analysis leaving 64 programs. Syllabus content, along with other relevant information such as Program Learning Outcomes, Module Learning Outcomes etc., are available for only 13 programs. In light of this low number and of the complexity of the syllabus information, the main analysis was conducted on the large proportion of programs - 64 - currently offered for which listings of module titles are available.

Two further programs were excluded from the main analysis and considered separately, as one has "Management" in its title and the other has "Business" in its title. Both were found to be genuinely multi-disciplinary in nature. This brought the number of programs in the analysis in this section down to 62. The two excluded programs are discussed separately below, together with a third multi-disciplinary program.

The number of modules of broadening content that fall into each of the categories identified, again based on their titles, was identified and inferences drawn regarding the extent and type of broadening content. A qualitative analysis of the descriptive material available on all programs was also carried out. The qualitative analysis was informed by syllabus detail where it is available.

Results of the Review of Professional Engineering Programs in Ireland

The number of programs at Level 8 and Level 9 containing 0, 1, 2, 3 or more modules of broadening content across the 4 categories introduced above are separately displayed in Table 3 and Table 4 below.

No. of Level 8 (Hons Bachelor) Programs containing:	**Professional & Ethical Development**		**Generic Skills**		**Core Business Topics**		**Other-Humanities etc.**	
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
0 modules in:	16	36%	12	27%	17	38%	45	100%
1 module in:	27	60%	17	38%	24	53%	0	0%
2 modules in:	2	4%	14	31%	4	9%	0	0%
3 modules in:	0	0%	0	0%	0	0%	0	0%
> 3 modules in:	0	0%	2	4%	0	0%	0	0%
Total	45	100%	45	100%	45	100%	45	100%

Table 3: Programs at Level 8 containing one or more modules of broadening content

No. of Level 9 (Masters) Programs containing:	**Professional & Ethical Development**		**Generic Skills**		**Core Business Topics**		**Other-Humanities etc.**	
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
0 modules in:	13	76%	11	65%	5	29%	17	100%
1 module in:	4	24%	6	35%	9	53%	0	0%
2 modules in:	0	0%	0	0%	1	6%	0	0%
3 modules in:	0	0%	0	0%	0	0%	0	0%
> 3 modules in:	0	0%	0	0%	2	12%	0	0%
Total	17	100%	17	100%	17	100%	17	100%

Table 4: Programs at Level 9 containing one or more modules of broadening content

Discussion

The most striking finding is that we could not find a single mandatory module from the arts and humanities included in any of the 62 programs considered. Nine programs include a modern language module as an elective. Two programmes in one university list a module titled "Service Learning & Ethics". No further details are provided. No instances of modules involving service learning / community engagement were found.

More than a third of programs at level 8 do not include a single mandatory module with a primary focus on either Professional and Ethical Development or Generic Skills (including work placement modules, or project modules with mention of generic skills). More than a quarter of programs at level 8 do not include a single mandatory module on core business topics. Some small mitigation lies in the availability of broadening modules as electives in the case of 9 of the 45 level 8 programs.

At Level 9, the picture is even more striking. Three quarters of programs at level 9 do not appear to include a single mandatory module on Professional and Ethical Development. Two thirds do not include a single mandatory module on Generic Skills. Some mitigation again lies in the availability of broadening modules as electives (alongside many technical and scientific alternatives) in the case of 9 of the 17 level 9 programs.

At either NFQ level 8 or 9, the number of programs having 2 or more mandatory broadening modules in any of the 4 categories is tiny, with the exception of generic skills at level 8 (35% of level 8 programs have 2 or more generic skills modules).

As previously stated, broadening content that is not reflected in module titles may be contained in core engineering modules. There may be development of generic skills or business knowledge in seemingly exclusively technical projects, for example. A review of the overall program descriptions, however, supports the evidence from the module titles that broadening content is thin. Table 6 displays the number of programs in respect of which there is any significant mention of intent to broaden beyond technical mastery in program descriptions or objectives in the published literature on the programs online or in print. The numbers are low.

The evidence from this high-level review leads to the conclusion that the academic engineering community in Ireland in general attaches a low priority to the development of a broader perspective in engineering students, beyond the technical and scientific, evidenced by and reflected in a low level of inclusion of broadening content.

Level	No. of Programs
Level 8	9
Level 9	9

Table 5: Number of programs with electives that include broadening options

	Professional & Ethical Development		Generic Skills		Core Business Topics		Other-Humanities etc.	
No. of Programs	No.	%	No.	%	No.	%	No.	%
Level 8	2	4%	11	24%	8	18%	0	0%
Level 9	2	12%	4	24%	4	24%	0	0%

Table 6: No. of Programs in respect of which broadening intent is expressed in the public literature

Relating the Review of Engineering Programs to the Taxonomy of Engineering Enlightenment

While we must be cautious relating the above findings to the proposed taxonomy of engineering enlightenment, on the basis that the publicly available program information may not be a true reflection of how a program is delivered, nevertheless the findings in relation to the 62 programs in the main study lend themselves to some confident assertions. If we were to consider only content from the humanities for broadening purposes, then the majority of engineering programs in Ireland are at level 1 in the taxonomy; i.e. the programs are designed and delivered to produce "I-shaped" engineering graduates. This is clear from the absence of arts and humanities content from the programs.

The situation changes to some extent when the social sciences are included. This includes content from the other three categories of Core Business Topics, Generic Skills (considered to be largely developed through experiential learning) and Professional / Ethical Development. Aside from two outliers in Generic Skills at Level 8 and 2 outliers in Core Business Topics at Level 9, no program has more than 2 modules, or approximately 4% of the program content, in any of the broadening categories.

It is reasonable to conclude that engineering program designers in Ireland generally exhibit limited acceptance of "instrumental justification" for the inclusion of broadening content in engineering programs, with the objective of improved communication skills, and that they attach scant importance or relevance to the higher levels of the taxonomy, concerned with locating engineering projects in the broader social context and with critical self-reflection on the meaning of life in a progressively engineered world.

Review of Accreditation Reports

The goal of this section is to examine evidence from the accreditation of Irish engineering programs in order to assess the opportunities for broadening of the curriculum and whether such broadening is occurring. We explore whether Irish engineering students (within professionally accredited programs) are being equipped for the roles that they will play in society. Is there evidence coming through Accreditation Visits that this is occurring? We also explore the evidence that exists from accreditation reports that engineering program leaders attempt to ensure that their students study engineering within an environment that supports critical reflection on the role of engineers in creating the society and the world we live in.

In general, the engineering curriculum is designed by engineering academics to meet learning outcomes set by accrediting bodies composed of professional engineers (some of whom themselves are engineering academics). The situation is further complicated by the view of both groups that rigorous engineering standards must be demonstrably met (because engineers are educated to work as engineers) and this has led to crowded curricula that act to push out what are seen as non-essential subjects (and by definition this includes non-engineering topics).

Engineers Ireland is the professional body for engineers in Ireland, with over 23,000 members. It has represented the engineering profession since 1835, and both protects and awards registered engineering titles, including the professional title of 'chartered engineer'. Registered titles from Engineers Ireland provide formal recognition of professional competence, including international recognition. Engineers Ireland is also the accrediting body for engineering education standards, and it conducts accreditation reviews against its published engineering accreditation criteria (Engineers Ireland). Engineering education programs undergo scrutiny every five years by independent panels established by Engineers Ireland. Engineers Ireland itself is subject to periodic reviews of its processes and criteria by an association of accrediting bodies – EUR-ACE (REF).

Accreditation has evolved from an 'inputs' model to one of evidence-based program outcomes (POs), and each program must be able to demonstrate that its graduates achieve these outcomes. Accreditation panels are generally experienced, in that members will have undergone training by Engineers Ireland, and may have participated in a number of previous accreditation visits. According to the Registrar of Engineers Ireland "we must recognise that this is a peer assessment so the assessment panel is looking to see if what they are assessing is *substantially equivalent* to the programs that they deliver in their own education institutions or if they deliver to the requirements of industry" (Owens 2016). Assessment panels comprise two academics and an industry practitioner. Panel members are not always engineers, but non-engineers, for example a medical doctor on a Panel reviewing a Medical Device degree, are additional to the Panel rather than substitutional. In addition to a preparation day, the accreditation visit is conducted over two days.

Accreditation based on outcomes is relatively new. Previously, engineering programs were accredited based on defined input criteria set by accrediting bodies. These minimum requirements typically included (i) "qualified, forward-looking and competent faculty; (ii) a defined curriculum (based on engineering discipline) that prescribed specific subjects and minimum durations for those subjects; (iii) quality and performance of the students on the program, including intake quality; (iv) critical facilities to support the program, including classroom space, laboratory space, workshop space, library, etc. [5]. With accreditation based on input criteria, the philosophy was that quality assurance on each of the inputs (such as minimum entry standards, minimum number of hours of study, required assessment, formalised accreditation processes) provided evidence of the quality of the program (effectively, good ingredients will make a good cake). Modern engineering accreditation criteria, based on program outcomes, rather than defined input parameters, are intended to provide greater latitude and freedom to engineering program designers, while also focussing on the abilities of the graduates emerging from the program. With accreditation based on outcomes, institutions can be innovative in program design and pedagogy but must be able to provide evidence that graduates meet the POs for their program. These POs can be tailored to institutional goals and the academic environment in which they will be delivered. In Ireland, "the pedagogy and method of delivery of programs is left to the HEIs" (Engineers Ireland).

The program outcomes required to satisfy the criteria for professional (chartered) engineer are as follows.

(a) Advanced knowledge and understanding of the mathematics, sciences, engineering sciences and technologies underpinning their branch of engineering.
(b) The ability to identify, formulate, analyse and solve complex engineering problems.
(c) The ability to perform the detailed design of a novel system, component or process using analysis and interpretation of relevant data.
(d) The ability to design and conduct experiments and to apply a range of standard and specialised research (or equivalent) tools and techniques of enquiry.
(e) An understanding of the need for high ethical standards in the practice of engineering, including the responsibilities of the engineering profession towards people and the environment.
(f) The ability to work effectively as an individual, in teams and in multidisciplinary settings, together with the capacity to undertake lifelong learning.

(g) The ability to communicate effectively on complex engineering activities with the engineering community and with society at large.

Discussion of Evidence from Accreditation Reports

Criteria (a) through (d) represent what can be termed the traditional core strengths of engineering, and can be considered as 'hard criteria' when viewed through a traditional engineering lens. Criteria (e) through (g) underscore the importance of contextual understanding and practice, and these may be considered as 'soft' criteria through the same traditional engineering lens. The criteria clearly support levels two (instrumental), three (enhanced instrumental) and four (intrinsic value) of the Taxonomy of Engineering Enlightenment (see Table 1 above). In this respect, the criteria can act as critical mediating factors that can focus the structure and curricula of engineering programs requiring accreditation. Significantly, Engineers Ireland goes further in terms of detail with respect to its criteria. Each criterion contains a description of what the engineering program should be able to demonstrate. For example, under Criterion (e) "graduates should have, *inter alia*: (i) the ability to reflect on social and ethical responsibilities linked to the application of their knowledge and judgements; (ii) knowledge and understanding of the social, environmental, ethical, economic, financial, institutional, sustainability and commercial considerations affecting the exercise of their engineering discipline; (iii) knowledge and understanding of the health, safety, cultural and legal issues and responsibilities of engineering practice, and the impact of engineering solutions in a societal and environmental context; (iv) knowledge and understanding of the importance of the engineer's role in society and the need for the commitment to highest ethical standards of practice; (v) knowledge, understanding and commitment to the framework of relevant legal requirements governing engineering activities, including personnel, environmental, health, safety and risk issues" (Engineers Ireland). Engineering programs providing evidence that their graduates have these abilities can certainly claim Level 4 on the Taxonomy of Engineering Enlightenment: that their program enables critical self-reflection on the meaning of life in a progressively engineered world, and that their graduates can both transform the world and can reflect on what it means for society. In a similar manner, fully satisfying Criterion (g) provides evidence of Levels 2 and 3 on the Taxonomy of Engineering Enlightenment.

All of the accreditation reports were for programs that had successfully demonstrated evidence to meet the seven criteria (a) through (g). In that respect, many different accreditation panels independently satisfied themselves by examining program and assessment evidence, interviewing current students, graduates and employers that all seven criteria were successfully met. This is an important point to bear in mind with regards to engineering programs in Ireland. It also suggests that the publicly available information describing programs is often insufficient in describing the strengths, often hidden, of a program and that it takes a more forensic accreditation panel to evince these strengths. For example, from the earlier Review of Programs, this example of critical reflection with respect to Criterion (e) would not be evident: "particular noteworthy examples include Professional Engineering & Communications … which examines 'wicked', multi-faceted problems requiring an examination of societal, political, technical, etc. issues to be recognised – assignment requires ethical reasoning to be emphasised." A different report from a different university notes "[project] work and in-depth discussions with staff assisted the Panel in assessing if this outcome was being met. Concepts such as integrity, environmental awareness and the likely impact of the graduates work on society is an integral part of a number of modules in all years".

However, it can also be said that the authors found no evidence of systemic attention to a broadening agenda within the accreditation reports. These reports indicate that often the same (few) courses within a program provide all of the evidence of meeting criteria (e) through (g), or that evidence could be found across a number of courses. It was often the case that accreditation panels found evidence in what might be considered arbitrary and non-rigorous forms. For example, "[on] the multi-disciplinary aspect, the programme benefited from the fact that students came from different backgrounds".

In reviewing all relevant accreditation reports, the authors looked for, but could not find, clear themes reflecting an institute-wide focus across its accredited programs with respect to criteria e, f, and g. In other words, we could not find evidence that any institution or university used these criteria to set itself apart, or differentiate all of its engineering programs – and therefore all of its engineering graduates – as different and unique. Certainly, where engineering programs shared the same broadening course or modules, the benefits extended to more than one engineering program. But this came across as coincidental rather than instrumental. Perhaps the closest to an institutional culture came from one traditional university with strong commonality across the first two years of its programs, and continued sharing of modules in later years. This might be considered as an *intra-engineering hybridicity*. As one accreditation report noted "[the] fact that students now are exposed to a common first semester gives them some insight into how other engineering disciplines work". More commonly, what was found was a clear focus on developing traditional engineering core values and strengths in graduates, for example the "primary aim of the programme is to produce high calibre graduates, who will possess a thorough knowledge of scientific principles and Engineering Practice and an appreciation of the industrial and business environment of the professional engineer". For a different program in a different institution "[the] primary objective is to educate students to become engineers who will be able to depend on critical reasoning to effectively apply qualitative and quantitative methods of inquiry to real-world problem solving".

Accreditation panels appear sometimes to try to highlight to institutions that elements of a program require attention, while not refusing that accreditation. For example "consideration should be given immediately to securing opportunities for teamwork in multidisciplinary situations". In another case "[for] future review exercises, the provision of explicit evidence of where these skills are being addressed should be provided". In yet another report: "[the] course team may have been modest here in preparation of the material available in the base room as there are likely to be many modules throughout the programme where students are required to work as teams". And again for another program: "[a] further general observation is that in some modules (namely "the engineer as a professional") there is very good evidence in the form of submitted student work. It would have been useful to have more information on what was asked of the students during this module (e.g. coursework spec or marking scheme)". As a final example, an accreditation report recommends that "formal assessment of ethics is conducted in the service modules (non-engineering modules)".

From the accreditation reports it is clear that within some institutions and universities there have been initiatives to broaden the engineering student's education at the program level, rather than by adding broadening, non-engineering courses. The evidence as to whether this is successful is not clear. For example, a program accreditation report for one institution notes: "Table … listed all modules as contributing to [criterion] (e) and so the evidence provided for all modules was examined in detail. It was evident that all staff members have strong ethical principles and high standards of professionalism and that these values are implicitly instilled in the students in the delivery of all modules. However, not all modules were able to provide evidence that this programme outcome was being formally and explicitly assessed".

Finally, in a discussion with the Registrar of Engineers Ireland that focused on criteria e, f and g, the Registrar noted that Accreditation Panels are becoming more experienced at seeking appropriate balance of evidence between the 'hard criteria' and the 'soft criteria' (Owens 2016a). Engineering students do grapple with societal issues, but often at a micro level. Hybrid programs such as *Engineering with Business* stand out with regards to meeting criteria (e) through (g). Other points noted by the Registrar were that a common gap in criteria evidence is that of students working in multi-disciplinary teams especially with non-engineers. The best broadening evidence comes from work placement courses, and community learning projects. "Student work placement allows students to experience the application of their engineering studies and this experience benefits their continuing undergraduate studies." (Owens 2016b) Critical thinking skills are generally assessed by interviewing a small number of students. It was noted that students in some engineering programs appear not to have the time for adequate reflection.

Within the United States, the engineering and technology accreditation body is ABET (Accreditation Board for Engineering and Technology). ABET today has a similar approach to accreditation and program outcomes as does Engineers Ireland, or indeed *vice versa*. In responding to "calls for more well-rounded engineers who would remain competitive internationally, ABET released its Engineering Criteria 2000 accreditation standards" (Flaherty 2015). With these criteria, student outcomes are often referred to colloquially as 'A through K' under Criterion 3. Criterion 3(h) states that for ABET-accredited engineering programs, student outcomes must include "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context" (ABET 2016). In mid-2016 ABET signalled that it intended to update its criteria "to ensure they match the reality of today's world, while leading us through the 21st century" (Rogers 2015). The existing eleven student outcomes may be reduced to perhaps six, and the explicit outcomes in 3(h) may change. Given the necessity of ABET accreditation as a value statement for engineering schools, the effect of changes in the EC2000 criteria in terms of program structures and content will be significant. Whether those changes continue to see a broadening agenda (in line with Mitcham's critique), or whether they will signal a retrenchment to disciplinary and core engineering is an open question at this time."

Issues explored with Leaders and Heads of Business Schools

The following commentary is based on a semi-structured survey of 'expert opinion' among Irish business deans and business program leaders within Irish institutions that also have strong engineering programs. The objective was to gain an understanding of the reality of interaction between engineering and business/management departments in terms of engineering program design, curriculum development and course delivery. The commentary is presented as a discourse reflecting the current state and modality of collaboration, together with a view on the factors inhibiting collaboration.

From these discussions with business school deans and business program leaders it is evident that there is wide variation with regard to both the intention and the practice of collaborative design and delivery of engineering programs at undergraduate level across Ireland. In many cases there is or has been an intention for a broadened curriculum to include business/management department courses. However, over time the inclusion of such models has become limited and is best characterised as informal and marginal with business courses that are available but of little interest to engineering students.

Business and management courses which are seen as 'not part of the engineering school culture or ethos' impact on their acceptance within engineering departments. Business deans described engineering programs as 'highly prescribed with very little elective choice', which therefore creates curriculum tension if trying to include non-core engineering courses. There is little evidence of formal collaboration in program or course design, or delivery, and where courses are available they tend to be offered via service teaching, as under-utilised electives, or often delivered by internal engineering department staff.

Business deans commented that most institutions express the view that the broadening of the engineering curriculum to include business /management courses is desirable, but perhaps is best delivered at a postgraduate stage, with the undergraduate program focusing on the students' core engineering education. As seen in the previous section, there is little program evidence that this is occurring. At undergraduate level, current practice is characterised by a 'nodding to business content' with little direct involvement of the business department in either the design or delivery of engineering programs. Business and management content in an undergraduate engineering program has a low priority, and also low interest among both students and staff involved in engineering programs. A contributing influence appears to be the development of a strong engineering identity among students at an early stage in their engineering program which seems to adversely affect the students' views of non-engineering courses.

Where business/management courses are available, they are typically offered as student sourced electives, via service teaching or as courses delivered from within the engineering department under a generic heading such as 'professional development'. In general, such courses have a low priority for students, they are 'not taken seriously', they are of 'little interest', and they are not seen as 'difficult or challenging'. Such views can lead to an under committed student who under-performs in their business/management courses creating a program difficulty if such courses are deemed as mandatory for progression. The reasons for such views probably reflect a gradual erosion of non-core engineering courses from the curriculum over time. Business deans spoke of curriculum space issues, different vocational cultures; and a noticeable dis-interest among engineering students and staff in non-engineering courses. The result is a 'squeezing out' or 'chiselling out' of non-core engineering courses from the curriculum over time. Programs that at one stage may have been designed to offer a broader curriculum have been subject to a normative effect over time.

Three primary reasons were offered for the current low level of collaboration between engineering and business departments in the design and delivery of engineering programs. In general three key reasons were cited:

1. The low-value perception of business/management among engineering students and perhaps engineering department staff. There is a prevailing view among respondents that engineering students view business and management courses as 'easy options of little interest', which lack credibility and are not taken seriously leading to reduced effort. The resulting lack of engagement and the failure to place such courses within an engineering context can partly explain the student antipathy which seems to exist.
2. The issue of curriculum space. A recurring and connected theme among respondents is that of curriculum space combined with the value students and staff place on business/management courses. There appears to be a continual tension in including non-core engineering courses within the curriculum. The extensive, intensive, focused and prescribed nature of undergraduate engineering programs combined with their perception of business/management courses as having lower worth mitigate against the allocation of adequate curriculum space to deliver business/management content at an appropriate level.
3. The issue of apparently different educational approaches of the two disciplines. The perception of engineering and business/management as coming from two distinct and different cultures is an inhibitor to collaboration. Whether the view is valid or not the influence is evident. Engineering students can be 'disparaging of business/management courses and don't take them seriously'. Among both engineering staff and students there is a question over the perceived credibility of non-engineering courses. The early formation of an engineering identity among students reinforces the perception and may be a contributing influence.

In the opinion of business deans, the broadening of the undergraduate engineering curriculum to include non-core courses and the collaboration between different disciplinary departments has always been seen as a desirable and worthwhile development – in theory. The practice however appears to be more difficult to achieve and particularly to sustain. The importance of communications, teamwork, people management, soft skills to complement the technical skills of the graduate is evident in the number of engineering undergraduate programs with a 'professional development' course within the curriculum. The question however remains as to whether a 'professional development' course is adequate to address of broadening the curriculum or embedding the required non-core skills. The view was expressed that the 'engineering student's perspective can be quite narrow' and that 'engineering students are technically very focused' due to the prescribed nature of many engineering programs. A broader societal perspective which contextualises the role of engineering in society could create a sounder educational experience for the engineering undergraduate. The inclusion of business and management skills such as interpersonal skills, communications, entrepreneurial, marketing and financial analysis skills were offered as useful additions to the undergraduate engineering curriculum.

Some respondents felt that the pivotal role of engineering in society required undergraduate students to have a broader educational experience characterised by a social sciences perspective rather than a narrow business and management perspective. Either way, the current and dominant narrow concentrated nature of many engineering programs with their curriculum and students focused on increasingly specialised core courses will not deliver the engineer whose role is to help solve the large problems faced by today's society.

The educational approaches and traditions of engineering and business have sometimes been characterised as opposites, the former dealing with technical, evidential and procedural based knowledge while the latter more involved with intangible, ill-defined, concept based knowledge. In reality, this dichotomy was never truly real, particularly for engineers who progressed from technical roles to operational and then strategic roles. Business and management courses with their use of broad problem solving case studies, problem based learning approaches and dealing with ambiguity could offer additional skill sets of use to the graduate engineer. In reality, such skills reflect the actual practice of the professional engineer, engaging in critical thinking, being a reflective practitioner and seeking workable solutions to ambiguous problems.

The inclusion of non-core courses in undergraduate engineering programs will require an acceptance by both students and staff of the legitimacy of such courses as well as the creation of adequate curriculum space. In part it will require a structural change in the design of engineering programs, but perhaps the biggest challenge will be the change in mind-set on the part of engineering students and engineering staff.

The existence of successful engineering based undergraduate programs which include innovation and enterprise in other jurisdictions such as the US should give cause for optimism and point to the development of a broader more societally based education model for undergraduate engineers.

Apart from the questions of curriculum space, the perceived value of non-core courses and the perceived 'cultural' differences, the status of the 'engineer identity' is perhaps the greatest inhibitor to the broadening of the engineering curriculum to include non-core engineering courses.

Hybrid Programs

Three programs with significant broadening content are outlined in the table below. The ME in Engineering with Business and the BAI in Engineering with Management are the two programs that were excluded from the earlier engineering program review, on the basis that their titles set them apart from the remainder of the engineering programs reviewed. The BSc in Product Design is a joint venture between three colleges within DIT: Engineering & Built Environment, Business, and Arts and Tourism, and is discussed in greater detail below. It is clear from the modules listed that the programs listed in Table 7 are true hybrids of engineering and business. Although they lack the creative elements found in the BSc in Product Design, or any content from the arts or humanities, they are clearly designed with broadening in mind. Refer to a later discussion on hybridity.

Program Name	**BSc Product Design**	**ME Engineering with Business**	**BAI Engineering with Management**
Institution	Dublin Institute of Technology (DIT)	University College Dublin (UCD)	Trinity College Dublin (TCD)
Accreditation	Institution of Engineering Designers	Engineers Ireland	Engineers Ireland
Broadening Courses	Economics; Marketing; Communications; Management and Strategy; Marketing Research; Enterprise Development / Business Process Management; New Product Introduction; Legal Aspects of Product Design; Marketing Case Studies; Professional Practice	Accounting for non-Business students; Entrepreneurship in Action; Management & Org Behaviour; Energy Economics and Policy; Professional Engineering (Finance); Professional Engineering (Management); Engineering with Business Thesis; Operations Management; Professional Work Placement; Business Information Systems Management; Marketing Management;	20% of courses comprise management subjects such as marketing, finance, quality systems, supply chain management, and human resources management

Table 7: Examples of Multi-disciplinary Programs

The accreditation report for the hybrid *Engineering with Management* programme speaks highly of the program, reflecting its findings. In this sense, the broadening evident in the program content, matches the findings of the accreditation review. The features and strengths of as reported in its accreditation include *inter alia*: "Students graduate with a very broad base of knowledge covering engineering subjects, ethics, financial and business skills; engineering and management is a very strong combination; … there is strong evidence of the building of interdisciplinary skills within the programme especially with the Business School".

For the hybrid *Engineering with Business* programme, the criteria e, f and g are all covered through multiple modules and via the work placement activity. Among the list of features and strengths of this hybrid program, the following are noted from among others: "The Engineering with Business Masters programme is unique in the country and staff and management must be commended for identifying this opportunity to support Irish industry. It was obvious from the visit that the programmes and staff were actively supported by senior management in the College and there was high morale among the Engineering Teams delivering the programmes, showing a caring ethos for students and overall welfare of the University". Here again, the very strong accreditation report regrading criteria e, f and g, matches the broadening evidence identified through the program review.

Detailed Discussion of one Hybrid Program – DIT Product Design

This section discusses one hybrid program that appears to be an outlier with regard to success in broadening an engineering curriculum. DIT offers a 4-year multi-disciplinary program in product design. While not accredited by Engineers Ireland, it is accredited by the UK Institution of Engineering Designers (IED). As such, it is not strictly in scope for this study. However, as an imaginative amalgam of core engineering content with substantial creative and business content, it is arguably one of the very few programs in Ireland conceived and designed *ab initio* as a collaborative program, and managed in a truly multi-disciplinary manner with engineering, arts and business disciplines acting as equals, rather than on a 'core' and 'non-core' basis. This program is used as a comparator with general engineering programs in terms of student perceptions in the section on the Irish Survey of Student Engagement, discussed below. It has been running in DIT for just over ten years.

Students study how the creative aspect of design integrates with the analysis and manufacturing process. Bringing a concept to market is covered in courses such as Economics, Marketing and Legal Aspects of Product Design, New Product Introduction and Business Process Management. Students are expected to enter national and international design competitions. The third year project "consists of an open-ended design brief to which … students are expected to apply design, engineering and business skills in order to produce a viable and marketable product" to a professional and industrial standard (O'Kane and McDonnell 2011). Another feature of the program, borne out of both compromise and necessity, is that students spend part of their week at the DIT Engineering campus, at the DIT Business campus, and at the new DIT Arts campus. "Of particular concern to the lecturing team was the aim of encouraging deeper learning through use of group work rather than previous approaches, which have tended to focus on retention and reproduction of material delivered in a traditional lecture setting." (O'Kane and McDonnell 2011)

To examine the degree of success of this program in meeting its aims, we turn to a recently introduced national student survey. In 2015 Ireland implemented a national higher education student survey. Students from the first year and from the final year of all higher education programs were surveyed. Nine engagement indicators (EIs) were surveyed including the following three for our purposes: *Reflective and Integrative Learning, Quantitative Reasoning* and *Collaborative Learning.* Each Engagement Indicator was assessed by a number of questions. The response rates were adequate for statistical analysis with a high confidence level in the results. Each Engagement Indicator was scored on a 60-point scale. A score of zero meant that a student responded at the bottom of the scale for every question in that Engagement Indicator, while a score of 60 indicates a student response at the top for every question. The results in the tables below show the resulting mean scores for all relevant students in each category. When considering these results it must be borne in mind that these are based on how freshmen and final year students respond to questions and interpret their learning.

Engagement Index	DIT Product Design (1)	All DIT Engineering programs (2)	All DIT programs (3)	All Irish Engineering programs (4)	All Irish programs (5)
Reflective and Integrative Learning	34	27.8	28.9	27.6	30.7
Quantitative Reasoning	22.9	22	18.9	23.6	18.8
Collaborative Learning	37.2	32.9	31.4	33	30.5

Table 8: Mean scores for 3 Engagement Indicators

Table 8 presents results for the DIT Product Design program, for all relevant DIT engineering programs, for all DIT programs (this includes engineering, business, applied arts, sciences, etc.), for all relevant engineering programs nationally, and finally all higher education programs in Ireland. The results indicate, that for these indicators, DIT Product Design students report significant higher levels of reflective and integrative learning and collaborative learning. For quantitative reasoning, it is also quite surprising that DIT Product Design students report scores that are marginally above the average of all DIT engineering programs, and on a par with all engineering programs nationally. Clearly these students do not believe that their program is not analytic. The two benchmark columns of "All DIT programs" and "All Irish programs" include all programs in the Humanities, Social Sciences, the physical sciences and engineering. Taken in this context, the results for the hybrid DIT Product Design program are remarkable.

Selected Student Survey Questions	DIT Product Design	DIT: Engineering	DIT: All Disciplines	National: All Disciplines
Connected your learning to problems or issues in society (During the current academic year, about how often have you:)	33.3	22.7	24.9	28.0
Examined the strengths and weaknesses of your own views on a topic or issue (During the current academic year, about how often have you:)	34.0	27.8	28.3	30.0
Tried to better understand someone else's views by imagining how an issue looks from their perspective (During the current academic year, about how often have you:)	37.3	28.6	29.4	32.0
Solving complex real-world problems (How much has your experience at this institution contributed to your knowledge, skills, and personal development in the following areas?)	42.2	34.7	29.2	30.0
Being an informed and active citizen (societal / political / community) (How much has your experience at this institution contributed to your knowledge, skills, and personal development in the following areas?)	27.4	22.2	22.4	36.0

Table 9: Survey responses to Selected Questions

Table 9 provides survey data in response to five questions (of the total of 66 questions) from the survey. Each student, in response to each question, could answer Never (=0), Sometimes (=20), Often (=40), Very Often (=60). The table values are the averaged values. The results for DIT Product Design are again remarkable. For each of the first four survey questions, the self-reporting students indicate scores significantly above their DIT engineering student peers, all DIT students and all Irish students. DIT Product Design students connect their learning to societal issues, they self-reflect, they sought to understand other's perspectives, and – remarkably – they solve complex real-world problems.

The final question is also illuminating in that they self-report significantly below all Irish students with regards to being an informed and active citizen, but still 5 percentage points above all DIT engineering and indeed all DIT students. With these results, the DIT Product Design students score Level 4 on the Mitcham Enlightenment Framework.

Tangible benefits of Hybrid Programmes for Graduates

Within the United States attention has been paid in recent years to the economic value of a college degree, and specifically to the return on investment in terms of the expected salary against the cost to acquire that degree. Research has been conducted by PayScale, a company specialising in salary benchmarking. "PayScale has ranked more than 1,000 U.S. colleges and universities, including private, public and for-profit schools, to determine the potential financial return of attending each school given the cost of tuition and the payoff in median lifetime earnings associated with each school" (PayScale 2013). The data analysed are for bachelor degree students only and a superficial review shows that the greatest return from investing in education to bachelor level comes from studying a technology degree. Six of the top ten universities are private and the other four public. Of interest, at the top of the list is Harvey Mudd College which has a distinct educational mission which is "to educate scientists, engineers, and mathematicians to be well-versed in the social sciences and humanities so that they better understand the impact of their work on society" (https://www.hmc.edu/about-hmc/mission-vision/). Number six on the list is the Colorado School of Mines (Mines) which has as its vision statement that "Mines will be the premier institution, based on the impact of its graduates and research programs, in engineering and science relating to the earth, energy and the environment … Mines is widely acclaimed as an educational institution focused on stewardship of the earth, development of materials, overcoming the earth's energy challenges, and fostering environmentally sound and sustainable solutions." As a final example, number nine on the PayScale list is Stevens Institute of Technology, where one of this chapter's authors received his postgraduate degrees, and whose focus is on educating a spirit of entrepreneurship in its graduates. There may therefore be some evidence that hybrid programmes, or educational environments that champion hybrid programmes, can generate graduates who command higher-than-average starting salaries.

Conclusion and Recommendations

This chapter has examined Carl Mitcham's claim that the greatest challenge facing engineers "is cultivating deeper and more critical thinking among engineers, and non-engineers alike, about the ways that engineering is transforming how and why we live" (Mitcham 2015).

Engineers Ireland criteria provides the means to address Carl Mitcham's concerns, including enabling critical self-reflection on the meaning of life in a progressively engineered world especially through criterion (e) and what is expected of engineering graduates. Engineers Ireland have developed a robust set of accreditation criteria particularly for the 'softer criteria' of ethical and societal implications, critical thinking, multi-disciplinarity, and communications. However the publicly available information describing engineering programs is often lacking in describing the strengths of a program, and it takes a more forensic accreditation panel to evince these strengths. Perhaps both the criteria are too new for programs to have fully evolved, and the accreditation panels not sufficiently experienced, broadly constituted and trained, but the consistent evaluation of program evidence is lacking. In this regard, Engineers Ireland could provide better guidance and also more consistency in how Accreditation Panels should assess criteria e, f and g.

It may also be the case that the link between the academic engineers teaching on the engineering programs and the professional engineers on accrediting bodies is too close: perhaps evidence of too restricted a gene pool. This link has been commented on in the wider sense of its implications for the university by Robert Paul Wolff in his 1969 work on *The Ideal of the University* (Wolff 1969) in which he argues that the ideal university should not be a training camp for the professions. It has also been argued that accrediting bodies should not be comprised solely of engineers but that they should also contain non-engineering lay people (Grimson & Murphy 2007).

There are a number of ways to address the concerns raised by Carl Mitcham, which set the context for this chapter. One is to reject Mitcham and to 'let engineers be engineers' and consequently society at large should mediate the technology the engineers produce. In this regard, supporting a vibrant liberal arts counterbalance within higher education, and indeed society, is essential. Such an approach would reinforce rather than challenge current orthodoxy, leading to a continued 'two culture' society .

It can also be observed that perhaps Mitcham has elided the individual engineer's responsibility with the collective responsibility of engineering to society. While the codes of ethics of professional bodies provide the rule book by which individual engineers should practise their profession, it is through the consistent application of the accreditation criteria by which collectively the profession itself can best be reoriented. "Ethics curricula have previously focused on microethics, the responsibilities of engineers and other researchers to each other and to the profession, rather than macroethics, the responsibility to society at large" (David Guston quoted in Kaplan-Leiserson).

A second way to address Mitcham's concerns would be to leverage the social sciences in instrumental support of engineers. For example, Zakaria, while noting that "a liberal education is out of favour", has stoutly defended the values and strengths of a liberal arts education, including how to write clearly, how to express oneself convincingly, and how to think analytically (Zakaria 2015). "American routine manufacturing jobs continue to get automated or outsourced, and specific vocational knowledge is often outdated within a few years. Engineering is a great profession, but key value-added skills you will also need are creativity, lateral thinking, design, communication, storytelling, and, more than anything, the ability to continually learn and enjoy learning—precisely the gifts of a liberal education" (Norton 2015).

A third way to address Mitcham's concerns is to increase the number of 'non-core' engineering courses within the engineering curriculum, i.e., to increase the hybridity of curricula. The degree to which undergraduate engineering programs can include more and more non-core courses in their curriculum and still retain engineering status is an important consideration influencing greater collaboration. Generally, engineering program leaders talk about the challenging need to meet accreditation requirements. Yet the Engineers Ireland accreditation criteria e, f and g call for a diligent approach to broadening the curriculum. In addition, the programs that appear to most clearly provide evidence of that broadening are the hybrid programs of engineering with business, engineering with management, and product design. Whether there can and should be a limit to the degree of hybridization in engineering degree programs remains an open question in Ireland.

The issue of hybrid engineering programs, and therefore the education of what might be termed hybrid engineers, leads inevitably to the concept of hyphenated engineers (e.g. entrepreneurial engineers, business engineers). It could be argued that this is in fact a continued evolution of engineering education and the initial hyphenated mechanical engineers, electrical engineers, etc. The formation of such hybrid engineers is problematic in two ways in that (i) non-engineers cannot create engineers, and (ii) engineers have a professional identity which is normative and generally acts to maintain the status quo for both how engineers are educated and what defines an engineer. As Meijknecht and Drongelen have said, "like the medical, the educational and the juridical professions, engineers constitute a tribe, with its own traditional set of values that are transmitted to the new members in a symbolic way during their initiation. Studying is a kind of initiation" (2004). The notion of *tribe* also reinforces the challenges discussed surrounding core versus non-core, or engineering versus non-engineering within the education of the engineer. To engineers, the fear of diluting the core identity of the engineer is a concern, and it acts as an inhibitor to the acceptance of a broader educational experience for engineers. Within the tribe what is not core, what is not engineering, has lower value, is of lesser importance. Mitcham also refers to *them and us* when he says that "Engineers, like all of us, should be able to think about what it means to be human" (Mitcham 2014). Broad accreditation criteria, such as Engineers Ireland's e, f, and g criteria, can act as powerful policy instruments to ameliorate the perception of *them versus us.*

Another important issue, although outside the scope of this chapter, is the system into which the engineer is placed after graduation – a system which has evolved to focus on unrestrained growth. Perhaps the one argument guaranteed to most disgruntle those who see unrestrained technological development as the source of societal and global problems - is that engineers are necessary and essential actors in humankind's search for a sustainable future. The world today, through the relentless development and application of technology, is currently consuming far more resources than is sustainable into the future. Before we argue over who gets to decide on what a better society is, we need to ensure that we will have a society to argue over. In other words, for those who would hold the engineer responsible for creating the problem, the fact is that the problem can't be solved without the engineer; or perhaps more accurately, that any solution without the involvement of the engineer would be sub-optimal.

Recommendations

As has been noted, the criteria used by Engineers Ireland in the accreditation of engineering programs are, in the opinion of the authors, reasonably adequate for the purpose of ensuring that professional engineers receive an education that provides them with the broad foundation necessary to maximise their contribution to society. These criteria are reviewed on a regular basis. In light of the groundswell of concern about this issue, led by the likes of Mitcham, and the evidence in this chapter that the balance between core and broadening content in programs currently offered remains very lopsided, however, a more fundamental review would now be timely. Professional body accreditation criteria play a significant role in shaping engineering education, and accepting Wolff's argument above that the ideal university should not be a training camp for the professions, are likely to continue to do so in the future. It is vitally important that they get "ahead of the curve", through a period of deep reflection on the nature of engineering education in a rapidly changing and increasingly complex environment. Needless to say, the exercise should involve as broad a base of contributors as possible. Engineering and engineers are in danger of becoming commoditised – cogs on a wheel. Who is best positioned to address this? Challenge the engineering profession on this. Control your own destiny or someone else will! Call for a philosophical debate on the role of engineering in a progressively engineered world, and consequential education of that engineer.

A more immediate issue is the manner in which the current criteria are applied. The evidence is that broadening is not taking place despite the existence of criteria that require it. The relevant criteria are clearly not being rigorously applied in program reviews. One possible explanation for this, as noted earlier, is the composition of accreditation panels. It is strongly recommended that accreditation panels should contain at least one and preferably two members from disciplines other than engineering. The chairs and members of panels should also be well briefed on the issue of the broadening requirement.

The most fundamental reform is required within the institutions themselves. Engineering is not alone in displaying a strong resistance to the development of multidisciplinary and interdisciplinary approaches to higher education, but it is arguably the most disadvantaged as a result. Elements of the technocracy that Veblen envisaged have materialised, but far from the welfare of humanity being entrusted to their control, engineers have very much less influence than Veblen imagined. The closed and insular nature of engineering colleges and faculties, and the resulting narrow technical focus of engineering programs and educational environments have undoubtedly contributed to this diminution in the role of the engineer from an expert on the wheel to a cog on it. The lack of diversity in the types of programs offered is a further indication that a major problem of "group think" exists. The first step towards effective reform must be a step increase in the volume of research into the outcomes and processes of engineering education across the world today. In tandem with this, and very likely supported by it, a much greater diversity of voices must be admitted to the design and delivery of engineering programs, and new structures must be developed that break down the barriers between engineering faculty and those from other disciplines in a sustainable way.

The final recommendation brings the focus back to the Irish situation. That the evidence on which this chapter is not comprehensive or rigorous has been acknowledged throughout. As a small, open, globalised economy with a relatively new, strong and diverse engineering base, but with the apparent problems outlined in this chapter, it is suggested that Ireland is a good test case for engineering education. It is strongly recommended that a more comprehensive and rigorous examination of the questions addressed in this chapter be carried out. Enable engineering education institutions to establish distinct and differentiated engineering educational experiences, resulting in a greater diversity of engineering graduates to better serve society.

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