NEW APPROACHES TO ENGINEERING IN HIGHER EDUCATION

Proceedings of the Conference

held on 22nd May 2017

Engineering Professors COUNCIL
The voice of engineering academics

IET The Institution of Engineering and Technology

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Preface

Professor Sarah Spurgeon OBE, *President, The Engineering Professors' Council*

It is always easy to imagine the world is heading for disaster. With the problems of politics , skills shortages and environmental threats, it would be easy to sink into a paralysis of despondency.

But we are engineers. Where other people see disasters, we see challenges. Where others surrender to inevitable ruin, we find new opportunities. As a society, we have imagined we are heading for disaster in the past, and yet, as engineers, we have always imagined the way to make the world better instead.

We recognise problems and stand up to them. This country – the whole planet – needs engineering solutions.

As a community of academic engineers, we sit at the frontier. As researchers, it falls on us to help create those solutions. And, as teachers, we must also create a taskforce of graduates who can help bring their own creativity to our aid.

We must turn our problem-solving expertise on our own profession to meet the impending skills emergency in this country.

The New Approaches Conference, which the Engineering Professors' Council was proud to convene with the Institution of Engineering and Technology, embodied that spirit. We saw first-hand how engineers turn their imaginations to new approaches.

This publication represents an abundant seam of innovation that was presented at the Conference and which has been captured to act as the inspiration for further invention, development and change. Ideas are not in short supply.

As Jeremy Watson describes in his foreword (see page 5), engineers need both hard and soft skills. We need to be radical in imagining that what has worked in the past could be made better. For example, we all know you need Maths and Physics to be a good engineer, but these are things we can help stidents to develop and they are not the sum total of what you need. We need students with the imagination to dream a better world and the skills to build it.

Today has placed a flag in the ground to say, we are prepared to think innovatively.

There are many people whose generous support and hard work should be acknowledged: all those who contributed to the conference and to the proceedings by submitting their papers; the IET, Nigel Fine and all the staff of Savoy Place; John Perkins for chairing the conference and the steering committee who organised it; and to all those individuals who attended the conference or are reading this and who will take forward these ideas into our institutions of higher education.

Foreword

Professor Jeremy Watson CBE FREng FRSA MSc DPhil CEng FIET, *IET President*

The 'New Approaches to Higher Education' conference brings together some of the world's leading innovators from engineering higher education – from those making their courses accessible and appealing to a more diverse and inclusive student base, to those no longer stipulating advanced qualifications in maths and physics in their entry criteria. Most are developing new integrated engineering courses focused on finding solutions to real-world problems, but all are rewriting the rule book on how they train the engineers of the future.

Engineering is no longer a set of different disciplines to be taught in isolation. Instead it is becoming a spectrum, with blurring boundaries between hard and soft skills, and types of education – and an ever-closer relationship with technology.

There is growing consensus that we need to promote a broader, more inclusive and future-proof view of engineering – seeing it as a profession rather than a sector of the economy.

For generations engineers have been solving some of the world's biggest problems – and universities and colleges have provided the learning and knowledge required for engineers to fulfil this role. So today, with the engineering profession facing some pressing and prevalent challenges, and more anticipated around the corner – it is crucial that engineering higher education is poised to adapt to attract and produce engineers who can continue to engineer a better world.

The UK's engineering and technology skills shortage and gap is well documented. The most recent IET annual skills survey found that 62% of employers believe that graduates don't have the right skills for the modern workplace. More worryingly, 68% said they thought the education system would struggle to keep apace with technological change.

As Brexit negotiations are yet to begin in earnest, it is difficult to predict what impact the UK's exit from the EU will have on the skills shortage. But at this stage it's hard to see any short-term benefits on the skills shortage and gap from the UK leaving Europe, and we must be prepared that, at least in the short term, it could exacerbate the situation.

One way the IET is helping to tackle the skills gap is by promoting the importance of work experience for engineering students in higher education. We are also hopeful that the new degree apprenticeship courses, due to launch in September 2017, will put a new and sorely-needed emphasis on gaining practical, on-the-job experience to enhance academic theory and knowledge.

Another big contributor to the skills shortage and gap, as the IET's #9percentisnotenough campaign has been highlighting, is that there are simply too few girls and women going into engineering – which is also having an impact on quality of output.

Other professions such as medicine are seeing the benefits of a more gender diverse workforce in terms of a wider talent pool, improved creativity and better customer insight. We need to harness these benefits for engineering by getting better at attracting more girls and women into our engineering courses.

Engineers are increasingly finding themselves working as part of interdisciplinary teams that require more than one technical specialism and a growing repertoire of skills. An electrical engineer working in the automotive industry starting their career today is likely to need a far wider breadth of skills than they would have done 25 years ago, including mechanical engineering, project management and advanced digital skills.

Also contributing to this 'skills bonanza' that we need from our future engineers is Industry 4.0, otherwise known as the 'new industrial revolution', which is expected to have a similar impact on society as the previous industrial revolution when railways and factories arrived en masse.

Technologies like virtualisation, robotics and 3D printing mean we'll be able to develop, prototype and make products quickly and at very low cost – which will redefine the economics of manufacturing.

And of course, we now have the promise of a long-awaited Industrial Strategy from UK Government – which all the political parties have signed up to in principle. It's vital that implementation of the Industrial Strategy transcends party politics. The opportunities for engineering are very significant – but so is the challenge in terms of skills.

The implications of all of this for the higher education sector are enormous. We need to equip people with skills that are emerging alongside the technologies that require them. You cannot have a factory in which people use robots to greatly increase their productivity without training those people in 'cobotics' – working with and understanding robots. People cannot use data to make machinery more reliable and effective if they are not trained to interpret that data. The manufacturing of the future will require a more highly skilled workforce than ever before.

The emphasis on creativity and digital capability will be far greater, and the UK will need engineers who have the intellectual, creative and practical prowess to keep up with an ever-increasing speed of product development and technological change. We need to train a new generation of engineers in skills that are genuinely relevant to the new industrial values of flexibility, technical advancement and on-going innovation.

Single discipline specialism and theory will no longer cut it in the modern world. Engineering needs to break down barriers, nurture creativity and work across disciplines to solve some of the world's biggest challenges and to embrace the opportunities that the Industrial Strategy and Industry 4.0 present.

All of these changes call for a very different approach to engineering higher education – and that is why the IET and the Engineering Professors' Council organised the New Approaches to Engineering in Higher Education Conference to hear from universities and colleges around the world who have not only acknowledged the need for change, but have already taken action and are seeing some impressive results.

How they do it elsewhere

Peter Goodhew FREng, *Emeritus Professor at the University of Liverpool and advisor to NMiTE*, Michael Stevenson and Jo Edwards, *NMiTE, Hereford*

Innovation in engineering education is not a new phenomenon but it has tended to be piecemeal. New approaches have been trialled and adopted in hundreds of institutions in dozens of countries, with increasing intensity since about 2000. It is the purpose of this paper to review what has been attempted and what has been achieved around the world, in order to provide a platform for the innovators of 2017.

In order to discuss change we need a datum. With apologies to the small number of exceptions, we will characterise engineering higher education in the second half of the 20th century in the following way: Engineering was taught principally via the medium of the lecture, supplemented by exercise classes and laboratory experiences, over a 30-week year. Typically, students would attend 20-25 hours of formal classes and spend up to one day per week in laboratories performing "closed" experiments (with known outcomes). The curriculum would start with "fundamental science", including mathematics for at least the first two years, and would be developed to have a greater emphasis on engineering as if science and engineering were two ends of a single continuum. The 3 years would culminate in an extended individual project, often conducted in the department's research laboratories. Although design featured as a taught subject, in most cases the students would neither work in a team, nor make anything. This might sound like a caricature but it actually reflects the experience of the vast majority of engineering graduates prior to about 2000. This is the background against which innovation must be considered.

Innovation has been defined in many ways, but a common theme is the process of translating an idea or invention into a good or service that creates value or for which customers will pay. Innovations in engineering education have usually been driven by the desire to add value, normally by increasing quality rather than by reducing cost. Creativity (the thinking of new ideas) has played only a very small part in the changes to engineering education, principally because most of the ideas which gain currency are not new, but have been taken from developments in pedagogy (the way children learn). Thus the analyses propounded by educationalists such as Piaget and Vygotsky tend to be heralded as "creative" when applied to the education of adults in universities, but they are certainly not new. There are very few references in this paper, partly because there is little published work beyond the anecdotal, and partly because a quick web search will reveal more than we can usefully put in a small number of references. For instance Vygotsky did not publish in English, so most readers will need to go to secondary sources.

Against the background established by our caricature above, we can see a number of generic areas in which innovation is possible. These include:

1. The entry requirements
2. The "content" – the subject matter of the programme
3. The ways in which students acquire knowledge and understanding
4. The activities which the student experiences

5. The timescale for education
6. The spaces in which education takes place

We will consider each of these in turn, and summarize our findings in the table.

1. Entry requirements

It has been conventional to require engineering students to have studied mathematics, and frequently physics, to a level equivalent to the A-level in England. In fact, because engineering programmes are offered (in the UK at least) by almost all universities and to students of a wide range of abilities and prior education, as many as 40% of students in the UK start an engineering programme without mathematics or physics at this level[1]. A number of institutions which would be able to demand mathematics of their incoming students have elected not to do so. These include UCL and Warwick. These institutions report that students without maths on entry succeed just as well as those with conventional qualifications. A number of other institutions worldwide have also elected to reduce the emphasis on mathematics.

2. The content

Our concept of what is engineering changes constantly. However, innovation has tended to be reflected in the introduction of new programmes - or new programme variants - rather than in large changes in the content of well-established engineering sub-disciplines (mechanical, civil, electronic etc). Thus, programmes in biomedical or biochemical engineering, software engineering, nuclear engineering and automotive engineering have been started, together with variants such as electrical and railway engineering. A quick examination of the UCAS web site will reveal the current range of variants.

Content is not specified very tightly by accrediting bodies and it is very difficult to track incremental changes in existing programmes, so it can only be our impressionistic view that the content of many established programmes (for example in mechanical engineering) has not changed very significantly even in the first decades of the 21st century.

3. The ways in which students acquire knowledge and understanding

This is the area in which you might expect to see the most rapid and recent change. The arrival of the internet and social media has opened up numerous new ways to access information. It could be argued that knowledge acquisition (KA) is immensely simpler now than it was even ten years ago, although the development of understanding, and the ability to organise and deploy information usefully, still requires expert assistance. There is also an increased awareness that individual students learn in very different ways. We might therefore expect the lecture to be dying out, to be replaced by an armoury of alternative KA techniques including problem-based learning, internet searching, Youtube, MOOCs, learning from peers, recorded lectures, MIT's Opencourseware, Khan Academy, reading books (yes, still!) and so on. The role of the academic faculty member would in these scenarios change to one of advising, curating and supporting student learning – effectively asking the students good questions. However, in our experience of many university engineering programmes this has not yet happened to any great degree. There is little evidence of a reduction in lecturing and only isolated outbreaks of significant use of

alternative KA techniques. These are highlighted in the Table. There is ample scope for further innovation in this area.

4. The activities which the student experiences

Our baseline student experience involved lectures, exercise classes, pre-defined lab experiments and a research project. Here there has been a plethora of developments, albeit rarely many of them in any one undergraduate programme. Among the new experiences available to 21st century students are interactive and flipped classes, recorded lectures, on-line material, games and simulations, working in a group or team (sometimes involving students from more than one year, or more than one continent), design-build-test projects (DBT), competitive team activities such as Formula Student, problem-based-learning (PBL), interdisciplinary and multi-disciplinary projects, capstone projects (often in collaboration with industry), Dragons Den-style presentations, constructive failure, raising sponsorship, leadership training and outreach work with children in schools. These pedagogical techniques could be classified as "experiential learning", in contrast to the passive learning typified by lectures and reading lists. We do not have the space to unpack each of these – again the interested reader will search the web – but some institutions which deploy them successfully are listed in the table.

Students must also be assessed and multiple methods are already in use. These include various types of exam (including multiple choice) and various types of report (often on-line). There is some scope for innovation but it is usually the case that "better" (i.e. more revealing) assessment is more time-consuming. For example, face-to-face oral assessment of individuals has many positive features but is very expensive in staff time.

5. The timescale for an engineering education

Over the past three decades the "normal" duration of a full-time undergraduate programme in the UK has shifted slightly from 3 years for a BEng towards 4 years for an MEng. There are plenty of examples around the world of longer programmes to reach graduate level, but not many of shorter. The Bologna process and the Washington Accord have shifted the emphasis away from time-on-course to output measures relating to the capability of the graduate. The further effect of substantial fees being directly charged to students (whether deferred or not) has been to focus attention in the UK on shorter, faster routes to qualification. These have been termed "accelerated" degrees and most proposed routes have relied upon the use of more than the conventional 30 weeks of attendance per year. It is of course quite straightforward to put 90 weeks of learning into two years rather than three: Few institutions do this, although NMiTE is currently proposing a model which involves a 46-week year. However, universities in The Netherlands routinely use 40- and 42-week years, so - as with most so-called innovations - this is already well established.

6. Learning spaces

Innovative student activities, such as those outlined in 3. and 4. above, usually require a different type of space. For example, if classes are to become more interactive there is a need for class spaces without fixed seating and if project-based learning is to be adopted spaces must accommodate equipment, tools and making-space. Several universities have reacted to this need with new and re-designed spaces for engineering. Among these are Liverpool with its Active Learning Lab, Coventry's Engineering and Computing Building, Sheffield with The Diamond and the Bergeron Centre for Engineering Excellence at the Lassonde School of Engineering in Ontario.

More detail of specific individual innovations, together with case studies, can be found in the booklets by Kamp[2] and Goodhew[3], the book by Goldberg and Somerville[4], together with the proceedings of the twelve annual CDIO conferences[5].

Among the largest group of recent innovators are the members of the CDIO network (currently 140 institutions in more than 20 countries). The CDIO movement (Conceive, Design, Implement, Operate[6]) is committed to active learning and emphasises employability skills. Other innovators have been more radical, but are less widespread or well-networked. For brevity and to make comparison easy, these and other institutions are listed in the table, together with their main innovations and some other data.

Institution/project	Country	Founded	Students per year	Key innovation	Notes
Aalborg University	Denmark	1974	1000	PBL	
Amsterdam University College	Netherlands	2009	300	Multidisciplinary, experiential, personalised studies	Liberal Arts and Sciences
CDIO [5]	Worldwide	2000	>10000	DBT, employability skills	Currently 140 universities
Coventry University	UK	2009	1000	Flipped classes, student-centred learning, new learning space, humanitarian engineering	See Graham [7]
EPICS	USA	1995	>5000	Multidisciplinary projects from non-profits, vertical teams including schools	Originally at Purdue, now 15 Universities and 35 schools
Florida Polytechnic University	USA	2014	500	Experiential learning, industry partnerships	
Harvey Mudd College	USA	1955	250	Interdisciplinary, experiential learning	Also offers liberal arts
Hong Kong University of Science & Technology (HKUST)	China	2012	>1000	Smaller technical content, more hands-on, leadership training	See Graham [7]. They offer "Engineering Plus"
iFoundry (Illinois)	USA	2011	>300	Student-centred innovation	Support to other degrees [4]
Jacobs University	Germany	2001	200	Interdisciplinary, entrepreneurship	
Lassonde School of Engineering	Canada	2012	900	New learning space	Renaissance engineer
Liverpool University	UK	2008	350	Active learning, new learning space	CDIO partner [6]
Minerva University	USA	2011	50	All online, with F2F in different cities	
Olin College	USA	1997	85	Project-based, with few lectures, assessment	[4]
Penn State	USA	1995	>100	Capstone project within Learning Factory	See Graham [7]
Queensland University	Australia	1996	200	PBL, professional projects	See Graham [7]
Quest University	Canada	2007	200	Block system, arts and science degree, interdisciplinary, collaborative, students design own programme	
Singapore University of Design and Technology (SUDT)	Singapore	2012	350	Design focus	With MIT
d.school (Stanford)	USA	2005	650	Design focus, experiential learning	Does not give its own degrees – supports others
Taylors University College	Malaysia	2010	150	PBL, Celebration of failure	CDIO partner [6]
UCL Integrated Engineering Programme	UK	2014	750	Multi-disciplinary scenario-based teaching	Only in 1st and 2nd years so far. See Graham [7]
Zeppelin University	Germany	2003	400	Social innovation, entrepreneurship, multi-disciplinary	

Some of the "early adopters" listed in the table are challenger institutions, and are distinguished not least by their survival, in many cases for decades. All of those in the UK and USA which offer named engineering degrees have been successful in having their awards accredited. Many of them have annual student intakes in the hundreds, indicating that their chosen methodology is scalable. Anecdotal evidence suggests that their graduates are highly employable and, where the evidence exists, it shows that the programmes are attractive to women, with several institutions reporting gender ratios close to 50:50.

Graham[6] has reported on the factors which have been responsible for successful change in engineering education and several of the institutions in the table feature in her review. She concludes that innovation only becomes successfully embedded when it is driven both from senior levels in the institution and by enthusiastic practitioners at the chalk-face.

Finally we will comment on what is perhaps a surprising omission from this survey: e-learning. Although e-learning (a phrase which carries a variety of meanings) has been talked about extensively for at least 3 decades, there are few examples – at least in engineering – where it has enabled radical innovation. Of course, at the margins, technology has been very helpful. It permits the storage of, and easy access to, recorded lectures, powerpoint presentations, in-lecture feedback, notes, quizzes, a few simulations and some number-crunching software. But it has been far less influential than the shift towards experiential learning, typified by DBT projects, PBL, team projects and interdisciplinary work, none of which – of themselves – require e-learning. That is one of the most encouraging messages from this survey: the education of engineers still requires face-to-face human interaction, between and among staff and students. Indeed, one of the less-well-publicised features of many of the innovative programmes listed in the table is their low student-staff ratio – in many cases at 10 or below.

Peter Goodhew would like to thank the team at NMiTE, Kel Fidler, Ruth Graham and colleagues at Liverpool and in CDIO for stimulating his interest in this topic.

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Accelerating the development of creative design engineers

Mike Cook MA PhD DEng(Hon) CEng FIStructE FRSA FREng

Synopsis

It is well recognised that the UK needs more Engineers[1 2 3 4], and that we need to find ways to raise the level of creative design capability[5]. Creative design engineers can solve complex urban and natural challenges. They do this by gathering evidence with which to understand systems, and systems within systems, applying ideas from multiple specialist disciplines, to meet or exceed client goals and humanity's needs. Such capability is essential to our survival.

There has been a response to this need in education and industry but we are struggling to make the crucial break-through. Industry engages with schools and universities to help raise design awareness[6], but this relies on individual relationships across many institutions and businesses. These are hard to forge and hard to translate into meaningful, successful experiences for the students. I believe that the time is right to create a Centre focussed on Creative Engineering Design[7].

The Centre would provide schools, universities and industry with resources and development opportunities for students and early career engineers. It would provide accelerated development in a focussed environment for creative engineering design experience.

Introduction

Here I am taking "Engineering Design" to mean the application of creativity, imagination and technical knowledge for the production of a planned outcome that meets a practical need. This goes beyond the analysis of a problem and requires the understanding of the physical processes at work. It includes the synthesis of ideas and their application in new contexts. It is a highly demanding activity that gets easier with experience but also requires a degree of aptitude and early-career support in order to develop the confidence to try, fail and try again.

My personal focus relates to design in the built environment. Over the past forty years as a practicing design engineer, I have recognised that our incoming graduates often have little or no knowledge of the engineering design process, only of calculations and analysis. They have good technical knowledge but have often lost sight of what inspired them towards engineering careers and have not developed a capacity for creative engineering design. They need a lot of development time post-graduation.

As a teacher of Creative Design to Civil Engineering students at Imperial College, I see students are hungry to learn about the real value of engineers and to develop much needed creative skills. These future engineers need to experience design projects with social, economic, environmental impact and develop new skills through experience of idea creation and problem resolution[8].

The industry and profession has been changing at such a fast pace that we now need to make a leap in the way we teach but schools, colleges and businesses cannot do this in isolation. Universities find it difficult to bring in teachers with the experience and teaching skills. In industry, it can take too long to learn on the job and many graduates have to focus on the detail rather than the bigger picture. It simply takes too long to translate a talented individual from student to skilled creative engineer. These people are so vital to us that we need to accelerate the process.

I believe we need a place where young emerging engineers, taken from schools, universities or practice can come together with their peers and gain intensive design experience learning multi-disciplinary, collaborative, design-skills. It would be a place to conduct research and develop into new approaches to accelerated development to help raise the value of engineers and support the development of a more effective and supporting built infrastructure. And, it would be a place that takes advantage of the rapid development of digital technology.

This paper expands these ideas further, looking at the essential components of the experience, and some ways that organisations might come together and help make a Centre for Engineering Design a reality. I hope that in considering the first steps we can provoke a debate, learn from each other's experience and start to make plans.

The case for the Creative Design Engineer

A "creative" design engineer brings a mix of vital talents to a design team. They will have a depth of expertise in a specialist field that allows them to contribute very specific insight to a problem. This specialism provides the lens through which they look at a problem, assess the best response and test the outcomes against the brief. They also need to have an underlying appreciation of the power of engineering to effect change for the good or for harm, and a sense of purpose that will drive them forward as agents of effective change. This needs to be fostered and encouraged as it drives their motivation to strive for newer and more effective solutions. They also need to have developed skills that allow the individual to harness the power of a group towards a desired outcome, to communicate the value of what they could do or have done, to inspire others to act. When these three attributes – technical knowledge, a drive to find the right solution and a desire to communicate - are under-pinned by experience, they are able to bring to the table a creative capacity to their engineering that brings real value.

How to develop Creative Engineering Designers

The three key words that I use when teaching Creative Engineering Design at Imperial College are "Inspire, teach, experience". It is crucial to inspire students to want to learn more, to show them the practical good that engineering can do, to show them positive outcomes that they can align with emotionally. It is perfectly feasible to teach students techniques that enhance creativity. It is essential to experience working in a collaborative environment, see how to behave in collaborating groups of specialists and communicate their thinking and solutions to others appropriately.

Why it is not yet working

This is a shared problem across educators, professions and industry that operate in the built environment sector. This means that it requires a shared solution rather than isolated approaches at each stage of an individual's development.

The quality of design engineering thinking is certainly starting to improve in some notable cases and the JBM has set an expectation that institutions will provide "threads" of design learning.

However, there is a shortage of skilled teachers to teach "creative engineering design" to the standards needed, they struggle to find enough quality local industrial assistance and they do not know how to measure success.

There is no suitably "academic" A' level that inspires deep engineering understanding and inspires school pupils to study and pursue a career in engineering. So creative minds are diverted into what are perceived to be more creative subjects like art and architecture. This means universities attract engineering students who have not developed a creative culture. There is pressure on schools to find ways to inspire young people into engineering, acquiring the "Engineering habits of mind".[9]

How to accelerate development

We need to provide the means for an intensified and unified experience to accelerate development - a Centre for Engineering Design in the Built Environment "CEDBE". The centre will be like a gymnasium where people can have a "work-out" and get fitter. It will provide real and virtual environments where people can congregate and work together creatively. See Fig 1.

The experience will involve working intensely on complex built environment challenges that demand diverse ideas, testing against required outcomes and assembling coordinated solutions on multiple levels. This will intensify design experience that could take far longer to realise in industry and would be very hard to replicate in schools and universities.

It will inspire and motivate self-driven learning, leading to greater depth of understanding as well as wider appreciation of context. Practical experience will help cement information into learning. This would accelerate the creation of the kinds of engineering that are of greatest value

In addition, the Centre would provide opportunities for teachers to acquire new skills, school pupils to be inspired into future engineering studies, university students to have collaborative design experience within their studies and engineers in industry to have far more intensive collaborative design experience.

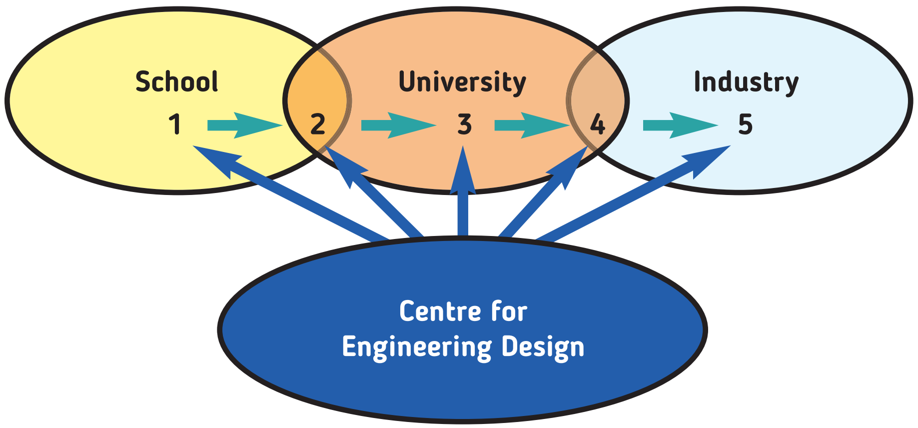

Fig. 1 A Centre working across five stages of accelerated development

1. Supporting in schools, developing early appreciation and making engineering tangible
2. Supporting universities in selection of individuals likely to succeed in engineering design environments
3. Developing engineering design skills and inspiring a desire to discover more
4. Supporting industry in selecting individuals that best fit their needs
5. Helping industry accelerate development of design capability in a diversely cohort of graduates

Examples of success

Olin College of Engineering[10]

Olin College of Engineering in the US has established its "collaboratory", dedicated to "co-designing transformational educational experiences with and for other institutions". They "join up leaders in education, business and government seeking to change education to spur the technical innovation necessary to take on society's big challenges." This is helping teaching institutions change the way they teach and inspires them to go through that pain of change. The "Olin way" encourages creativity in every aspect of the student experience. It emphasises the need for fun and for students to be able to influence the direction of their work.

Constructionarium[11]

In 2002 a project was started that has made a big impact on the education of engineers and giving them hands on experience of the act of creating big-scale engineering projects. The Constructionarium was borne of some visionary thinking meeting a clear business need. Contractors and consultants could not find engineers who really understood the act of engineering. So industry had to do a lot of development work on emerging graduates which cost a lot of time and money.

The Constructionarium allows students to go to a Centre where they spend a week planning and undertaking the construction of towers, masts, and bridges at large scale. They experience the real trials and tribulations of programming, budgets, health and safety and team-work. They discover that real engineering construction is a multi-faceted team activity. Most importantly, they discover it is exciting, stimulating and something worth building a career around.

Cambridge IDBE[12]

In Cambridge, the Institute for Sustainability Leadership runs a Masters in "Interdisciplinary Design for the Built Environment". This provides a valuable location for people from industry to gather and develop their skills across a broader front that might be possible back in their work-place. Their employers know that they will come back rejuvenated and with a valuably widened perspective on what they do and what their future could encompass. This demonstrates the value of short-term experience and exposure and shows that employers are willing to invest. Yet it cannot provide this for the range of age groups that need it and it operates at small scale.

How is the Centre for Design different?

The Centre would provide a place where young emerging engineers from schools, universities

or practice can come together with their peers and gain intensive design experience in collaborative groups on inspiring challenges, practising creative thinking and gaining real insight into the processes they need to use. Supported by academic and professional institutions as well as by consultants and contractors this could have a profound impact on the quality of UK's engineers and the quality of our built environment.

The Centre would provide short (from one day to two weeks) design workshops with a longer-term guided study syllabus leading to supplementary qualifications/certification. The Centre would undertake research into engineering design education, publish guides for schools and institutions seeking to raise their own capabilities and become a voice of built environment engineering education.

The rapid development of digital technology has changed the way we understand the built environment and can change how we teach. Technology is providing ways to reach a wider cohort of people who can collaborate remotely through shared models, real-time communication and on-line workshops. This has the potential to make the Centre highly effective and reach out to many thousands in ways that has not been possible before.

How could this become a reality?

The Centre for Engineering Design in the Built Environment (CEDBE) would learn from the Constructionarium and other centres. It would not be about physical construction but about design for the built environment engineering at all scales: cities, districts, infrastructure and buildings. It would be about the human, economic and environmental impact of engineering and the development of the skills needed to succeed in this space. It would be organised to inspire people in the vital importance of an engineer in society and to help them discover the tools they need to engage in this valuable profession. It would teach them the value of collaboration and give them the tools for creative thinking.

The Centre needs to be co-owned by people that need it – industry and universities. It might be seen as an equivalent to the Future Cities Catapult and could spawn multiple centres.

Initially it could exist as a "summer school" based at a supporting university and seed-funded by industry and academia. This could provide a "proof of concept" and demonstrate the level of interest. The funding would enable the teaching and supporting staff to run short courses at different levels over a period of up to six weeks. Attendees would fund accommodation and contribute to costs. A fruitful area for focus could be school students a year ahead of university entry where they can raise their skills and demonstrate a level of design understanding to potential universities where they are competing for places. This would also help universities in their selection.

Concluding comments

There is abundant evidence that educators and businesses understand the need and they are doing something about it[13 14 15 16 17]. Our professional institutions and academies are providing support in various ways. However, the results are fragmented. There are activities in many places with varying degrees of success. I believe we need to pull these efforts together. We all recognise the need to provide inspiring, practice-based, creative engineering experiences at every age group if we are to attract and retain enough people with enough enthusiasm, drive and skill to become valuable engineers for life. A Centre that provides access to this for all age groups at any time would provide the big step forward needed to accelerate the process for developing these creative design engineers.

These skills, combining technical and analytical capability with creative design and collaborative attributes, are what engineers need to meet society's needs. This is what employers are looking for and strive to find. Creative Design Engineers have real value and are well worth the investment.

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Vertically integrated projects: transforming higher education

Professor Stephen Marshall, *University of Strathclyde*

Let's start with a controversial statement: **The current structure of university courses means that our undergraduate students are being prevented from achieving their true potential.**

Ask yourself why the most ambitious people like Messrs Gates, Branson and Zuckerberg failed to complete their degrees. The answer is that they were eager to work on the difficult stuff and did not want to sit passively in lecture theatres all day.

So what are we doing wrong?

The answer is summed up in one word **compartmentalisation**.

Look at any successful organisation in any market sector and you will see a range of people, at different stages of their careers, from different backgrounds working together to a common purpose and communicating effectively across these boundaries.

So how do we prepare our young people for this world of work?

We currently prepare them by only allowing them to work with students in the same academic year and the same course. So they are, with a few exceptions, the same age, and possess the same basic knowledge. There is no understanding of hierarchy or specialism.

We even keep the research staff separate from undergraduates whereas the staff are in fact, ideal role models. In some institutions the most research active academic staff never come into contact with undergraduates.

How do we teach students to tackle big challenging projects?

We do this by fragmenting their education into academic years so that no single piece of work can last more than a few months before we get them to write it up and move on. Then we start all over again with a different group of students.

So how do we break this cycle and give our students the education they deserve and which will benefit the country as a whole?

All educators in all countries talk about more cross-disciplinary/multi-disciplinary, research-led, and peer-to-peer learning, but how do we actually deliver it?

The answer is Vertically Integrated Projects, or VIP for short.

VIP has been honed over many years in the US (vip.gatech.edu) and in the last 6 years has been implemented at University of Strathclyde (www.strath.ac.uk/viprojects) not just in Engineering but right across the curriculum. There is now a consortium of VIP active Universities led by Georgia Tech of which Strathclyde is a founder member (consortium.vip.gatech.edu).

In VIP, the traditional barriers between courses, academic years, academic generations, and research/teaching are broken down. This not only produces excellent education and employment-ready graduates, it also delivers real scientific and sociological advancements.

There are millions of undergraduates in the country, they represent a great untapped resource whose efforts can be channelled to the public good given the correct time, context and mentoring.

In 2012 the University of Strathclyde launched its own VIP program and now has over 200 students engaged on 9 projects ranging from hard science to English Literature to International Development. This builds on the ethos of *Useful Learning* evidenced by the recently opened £89 million Technology Innovation Centre.

So what are Vertically Integrated Projects?

VIPs are projects, led by academics but engaging 10-25 students from different courses and different years. The students receive academic credit for their participation in VIP, which corresponds to around 1/6 of an academic year.

The projects run over several academic years with the senior students graduating, the junior years advancing into more senior roles, and new students joining. They gain direct experience of leadership, planning, communication, research, conflict resolution and fund raising.

VIP students are in demand by employers because they realise that these students can rapidly adapt to the workplace. Non-VIP students can take years to learn how to function in a multidisciplinary environment.

VIP is not an end in itself, it is a vehicle to both unlock and channel the energy and potential of the vast community of undergraduate students. The current focus on Global Challenges is a perfect forum for students from different disciplines to come together and realise real benefits, VIP can be the mechanism to deliver those benefits.

In addition this, Vertically Integrated Projects have been demonstrated to be Multi Disciplinary, Cost Effective, Scalable and Sustainable.

The following pages provide examples of four Engineering VIPs at Strathclyde.

In addition to the roll out in Engineering the benefits of VIP have been demonstrated in other disciplines including Entrepreneurship, English Literature, STEM Education, Drama and the Life Sciences[1 2 3].

Examples of Vertically Integrated Projects in Engineering

Drug Discovery Project

The Drug Discovery Project started as Polarised Growth in 2012 and brings together students from Biology, Image Processing and Maths to model the behaviour of Streptomyces Growth and improve yield. The new Drug Discovery VIP uses Hyperspectral Imaging to identify new antibiotics.

Rover VIP

The goal of ROVER is to design, build and develop completely autonomous, robotic vehicles to enable environmental sensing and interaction in the environment and the smart cities of the future. The project goals are flexible between years and will educate and train students in any aspect of robotic systems relevant to their interests and discipline.

Sustainable Energy for Development SE4D VIP

One in five people in the world live without access to electricity (1.2 billion people). The United Nations' have sought to engage the international community in addressing this global issue by

setting a Sustainable Development Goal (SDG No.7) dedicated to ensuring access to affordable, reliable, sustainable and modern energy for all. The challenge has an added dimension when considering the international community's drive towards a global low carbon economy, and the need to ensure that our environment is not compromised in the pursuit of this energy access goal. Meeting these challenges has been the inspiration and driving force for the Sustainable Energy for Development (SE4D) VIP at Strathclyde. The SE4D VIP recruits undergraduates from across the University each year to make their own contribution to this global challenge. This contribution has focused on the design and development of reliable and sustainable off-grid renewable energy systems that can provide affordable electricity for some of the poorest and most vulnerable communities in the world, harnessing the engineering and economic expertise of UoS staff and students to innovate in the areas of power system design, ICT technology and business management.

Example of long running VIP at Georgia Tech

The eStadium VIP employs an array of sensor networks to deliver real time information to smart phones during American Football games. This is all run by students and now attracts substantial advertising revenue.

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Industry-ready graduates through curriculum design

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Abstract

Institutions that provide degree courses which demonstrate high employability and high graduate starting salaries will be more attractive to prospective students, and within the changing funding environment are likely to command the greater opportunities to access available funding whilst also satisfying the assessment criteria of the Teaching Excellence Framework (TEF). However, achieving these goals is becoming increasingly challenging - with engineering employers having expressed dissatisfaction with the output from Universities due to the lack of industry readiness of graduates, and the consequential shifting focus towards Higher and Degree Level Apprenticeships.

This paper explains the decisions and actions taken to produce a degree course which develops the technical ability required of an engineer, but also develops the confidence, self-belief and professional behaviours which are required for the graduate engineer to function within an industrial organisation. This can be described as the difference between 'knowing engineering' and 'being an engineer'.

In order to deliver this dual requirement, a new approach to curriculum design was deemed necessary and so it was necessary to create a new curriculum from first principles. Utilising a pull-centric process-based model to ensure that the curriculum is designed from the perspective of being a 'delivery process', which incorporates a combination of learning streams that are designed to achieve a series of capability outcomes. The pull-centric nature of the learning process dictates that the learning programme is developed in reverse order with the final 'output' capabilities dictating the prior 'input' learning need. This logic ensures that the learning at all levels is relevant and valid.

It is anticipated that this course programme will guarantee a minimum threshold of capability across the student cohort.

Keywords: Curriculum design, curriculum map, engineering education, TEF, employability, graduateness, capability

Introduction

Institutions that provide degree courses which demonstrate high employability and high graduate starting salaries will be more attractive to prospective students, and within the changing funding environment these same institutions are more likely to command the greater opportunities to access available funding whilst also satisfying the assessment criteria of the Teaching Excellence Framework (TEF). However, achieving these goals is becoming increasingly challenging - with engineering employers having expressed dissatisfaction with the output from Universities due to the lack of industry readiness of the graduates[11] and the political shifting of focus towards Higher and Degree Level Apprenticeships. The challenges for Engineering HE providers are therefore to beneficially differentiate their output from these apprenticeship programmes and to provide an education programme and qualified capability that matches with post-millennial expectations[7] and employer requirements.

Whilst working to achieve this, curriculum designers' are required to address a number of contributing factors which have traditionally had a negative influence on achieving this desired programme output.

One such barrier relates to the traditional 'bottom-up' curricular development model[6], where the standard approach to Higher Education (HE) delivery is through the use of a series of discreet modules, with each module assigned to a single academic member or team - with the module owner then deciding upon the content, delivery and assessment, often directed by the preferences of the deliverer. These decisions will normally be based upon prior practice, usually with the needs of the programme considered as a secondary requirement, and often result in modules in which the content is skewed by personal preference. Further, there is also a generic assumption that the synthesis practiced by students during the later stages of the course will just happen, with little thought as to how, where and when.

Another condition, which has a particular relevance to STEM subject areas, is the 'shelf-life' of knowledge. It is accepted that science and technology subjects evolve at a rapid pace and therefore facts, knowledge and theories can become out-of-date quite soon after graduation, certainly within the first 10 years of employment. Therefore, any course that prioritises knowledge over capability will have a limited value for both graduate and employer. In the circumstance where the capability development focusses on professional behaviours, practices and lifelong learning, the knowledge base and therefore positive contribution made by the graduate will be continually refreshed.

This paper explains the decisions and actions taken to produce a new engineering learning programme model designed to achieve a threshold of industry ready engineering capability at graduation through mitigation of the risks previously identified.

TQM for curriculum design

In order to create a curriculum, which extrinsically develops the threshold of industry ready engineering capability in all graduates, a new approach to curriculum design is required. The project to design a new curriculum has been considered from first principles, from the perspective of industrial quality assurance management i.e. $y=f(x)$, which recognises that variation in the outcome of a process is caused by variation in inputs to the process and process influencing factors[5]. Therefore, variation in the industry capability of the graduate is caused by variation in the learning programme and in its inputs.

In order to manage the variation to ensure achievement above a capability threshold, the process, process inputs and process influencing factors need to be correctly specified and controlled. This curriculum design process must therefore ensure that the correct specification is identified and maintained and that poor quality practice is prevented.

In some fields of study, it is normal to assume that if 'results' are acceptable then the 'process' itself must be working. However this logic provides no guarantee that the future results will be acceptable as the process to deliver them is unknown or un-controlled. The Process Quality Model proposes that control of the 'Process' will provide the 'Results' ($y=f(x)$), this is illustrated in the Process Quality Model (Figure 1).

Figure 1. The Process Quality Model

Creating a process-based curriculum, which is designed to deliver specific outcomes, must be developed as a pull-centric process-based model. The pull-centric nature of the learning process dictates that the learning programme is developed in reverse order with the final 'output' capabilities dictating the prior 'input' learning need. This logic ensures that the learning at all levels is relevant and valid by providing a mechanism that also ensures that content which is not required is not incorporated (for example, topics that would typically be justified solely on the basis of historical inclusion). The implementation of this relies on a top-down approach[6], to ensure that the whole programme is cohesive and delivers progression. The start point of this process is the definition of outcomes (Figure 2).

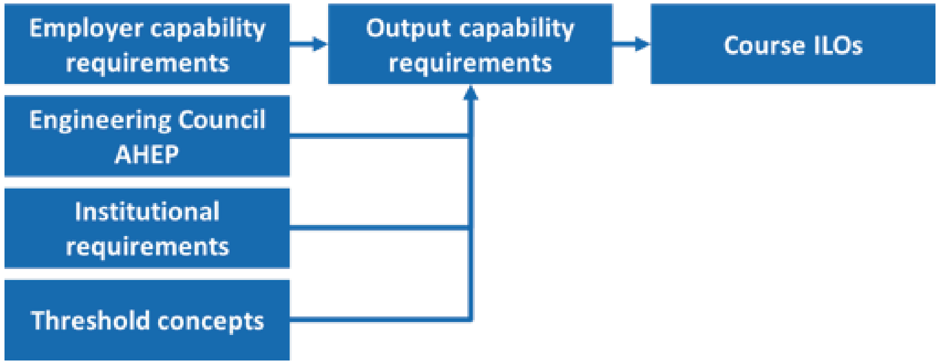

Figure 2. Source of Programme Capability Outcomes (adapted [4 10])

If one considers the diagram below, which illustrates the developmental journey of the learner, and then reads this in reverse: in order for the graduate to function in an employed professional role they need to have the knowledge and capability to know what to do and to make correct decisions. This phronesis is gained through progression through the programme, illustrated here using a modified version of Bloom's Taxonomy of Educational Objectives (Figure 3).

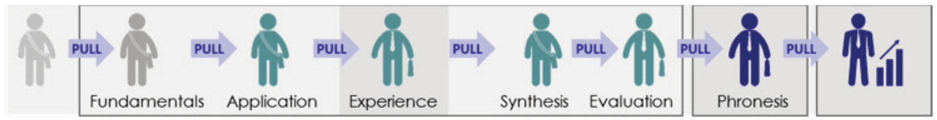

Figure 3. The developmental journey of the learner

Feedback from employers has confirmed that within any profession the subject knowledge alone does not provide sufficient capability to function effectively in a given role. Being able to recall information does not guarantee success and certainly does not enable an engineer to engage with others. Engineering is an applied science and therefore knowledge of the science is insufficient without the ability to apply the knowledge to a situation. It is proposed that the application, implementation and organisational skills have always had a greater impact on success than the knowledge elements. Normally this application and behavioural development is gained during employment, and is often learned through observation of others and trial and error.

The Accreditation of Higher Education Programmes[1] standard supports the view that industry ready capability requires the graduate to have not just a strong technical ability but also the professional behaviours that are required for the graduate engineer to function within an industrial organisation. This can be described as the difference between 'knowing engineering' and 'being an engineer'.

Subject knowledge and subject professional behaviours are learned in different ways and require different methods and practices for learning, practice and retrieval. The extended learning taxonomy model (Figure 4) illustrates the parallel development of these two core contributing factors. It is also recognised that in order to fully access the learning provided, and to function effectively as an Engineer, the graduate will require both motivation and self-belief as enablers for learning and engagement. An undergraduate lacking sufficient intrinsic motivation and/or confidence, will lack the resilience, or 'grit' required to fully engage with the challenges faced when problem solving.

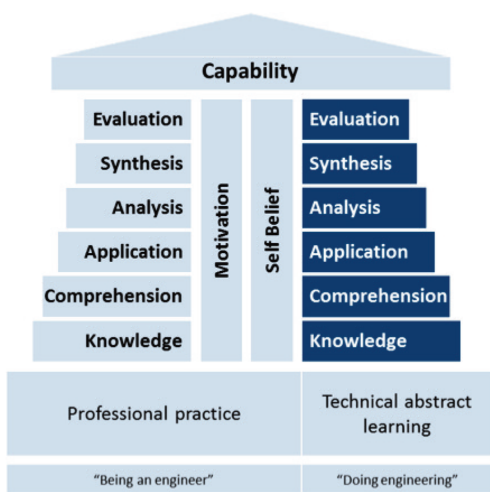

Figure 4. The Extended Learning Taxonomy Model (adapted [2])

It is therefore proposed that capability is dependent upon higher-level competence in both of the learning areas and in the two enablers. Recognising these additional requirements is important in developing an increased industry ready engineering capability at graduation.

This resulting pull-centric process based curriculum model is illustrated below, showing the two primary learning streams (behaviour and technical). The diagram illustrates the learning streams, and the 'keystone' final year project (which combines the streams and hence demonstrates capability), the initial employment phase, and the development to chartered status.

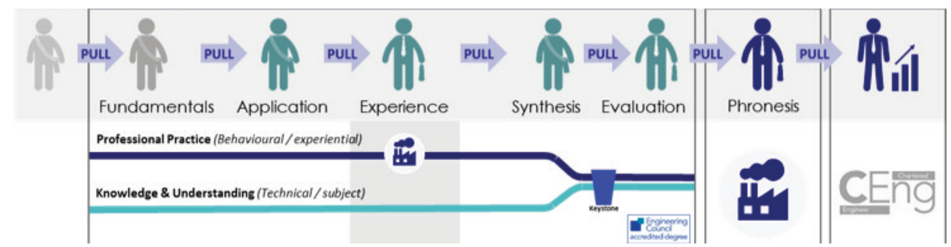

Figure 5. The pull-centric process based curriculum model

As the two learning streams differ in purpose they will need to be structured in a manner appropriate to maximise the learning gain, as follows:

- The **knowledge stream** (light blue) focusses upon the development of the knowledge and understanding of the subject specific theories, tools, techniques, etc. This knowledge is cumulative and assimilative, mechanistic, contextually relevant and learning is developed through experiential reinforcement. This knowledge and understanding enables the students to **do engineering**.
- The **professional practice stream** (dark blue) provides the learning into methods, practices, procedures and behaviours. This learning is structured in application, in a scaffolded learning environment, with predetermined outcomes and is facilitated experiential learning. This process is an experiential "learning journey". This knowledge and understanding enables students to **be an engineer**.

The knowledge stream can be further viewed as a combination of two sub-streams - core engineering knowledge and field specific knowledge (Figure 6).

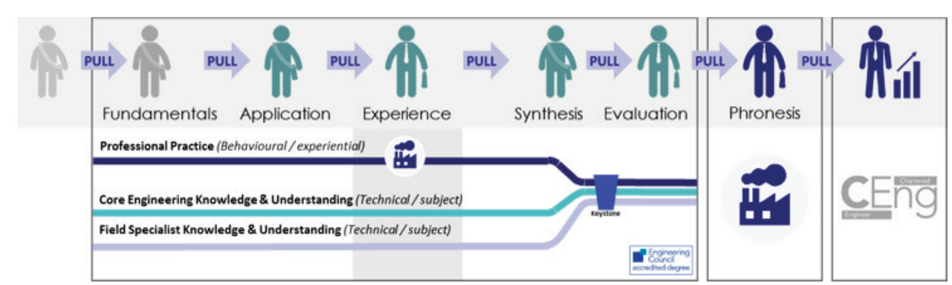

Figure 6. The pull-centric process based curriculum model – extended to include field specific knowledge.

The first of these two sub-streams provides the core engineering knowledge and understanding required by the Engineering Council. This stream contains the learning content which will enable the student to apply mechanical engineering theories to a given application. The second sub-stream focusses upon the field specific knowledge and understanding required for a graduate to apply the engineering core knowledge into a specialist field (with capability output specified by industry). When combined the learning gain from these streams forms the Engineering Knowledge required by the field of engineering.

Having selected the most appropriate means to construct the learning streams, the next challenge is to devise the most effective way to enable the learning in each of these streams.

Typically, degree programmes are based upon the delivery of knowledge based learning as discrete, separate modules in which content is grouped by field - such as hydraulics, electronics, mathematics, thermodynamics, etc. In this model, students learn the theory then practice some application as reinforcement.

The practice of engineering, however, is essentially problem solving and most often involves the selection and application of the most appropriate technology to a given situation. The knowledge and understanding elements of the field revolve around knowing which technologies could be selected, and understanding the relative benefits and risks associated with each technology, and selecting the best for the given problem. In the new curriculum model the core engineering theory, technology, etc. has therefore been grouped by application so that the knowledge retrieval is application based rather than technology based. Furthermore, subsequent modules are designed to combine and reinforce prior learning, for example: the module *Instrumentation and Control* is preceded by the two modules *Measurement and Actuation*. By this means the learning is logically sequential and more readily accessible. This is illustrated in Figure 7, with an example of a fully implemented curriculum map provided in Figure 8.

How will this curriculum model mitigate the identified concerns?

Implemented effectively this curriculum model will provide for a more deliberate and focussed outcome. The programme of learning will define output capability expectations, ensure that content and level match output capability expectations, and thereby drive learning gain in a holistically planned manner to ensure that the following issues are mitigated (and hence ensure a minimum threshold of capability across the student cohort).

Competition from other learning providers

Ensure graduate level employability by locking employer relevant content into the delivery, and designing learning programmes to meet the needs of identified graduate career roles.

Loss of engagement through inability to see relevance of content

The validity and authenticity of the learning plan is evidenced by an explainable curriculum map with an observable relationship between content and employment opportunities, and being able to demonstrate how learning builds towards a designed outcome. It is normal for some students to struggle to engage with the learning unless they can understand and accept the relevance. In those instances where the course team have confirmed the relevance of the content with respected employers, and demonstrated this to the students, it will be accepted.

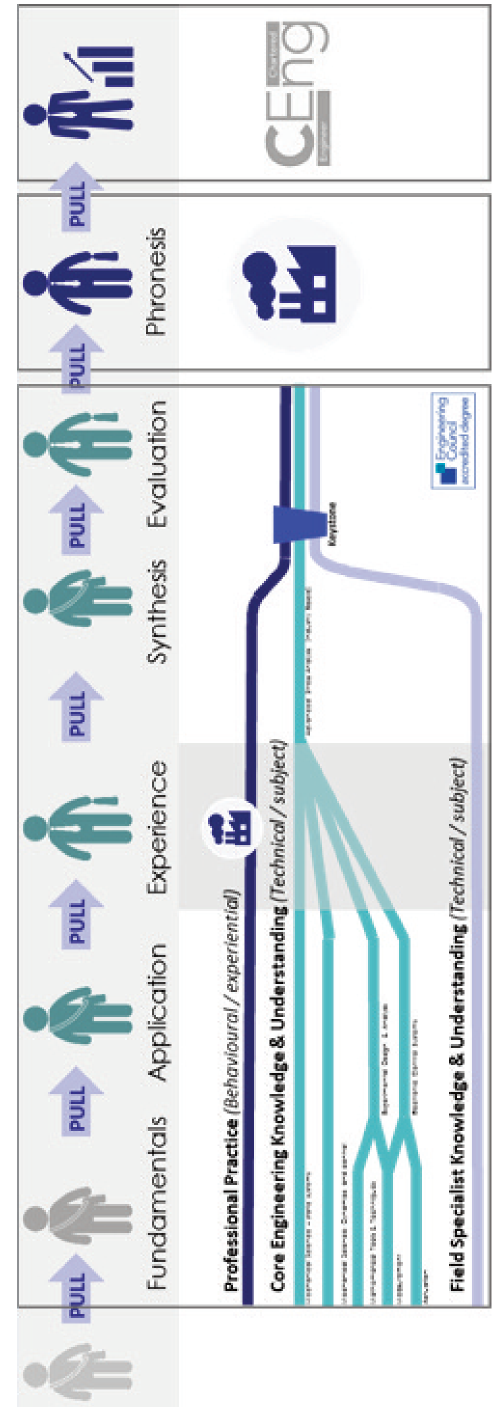

Figure 7. The pull-centric process based curriculum model – extended to core engineering knowledge breakdown.

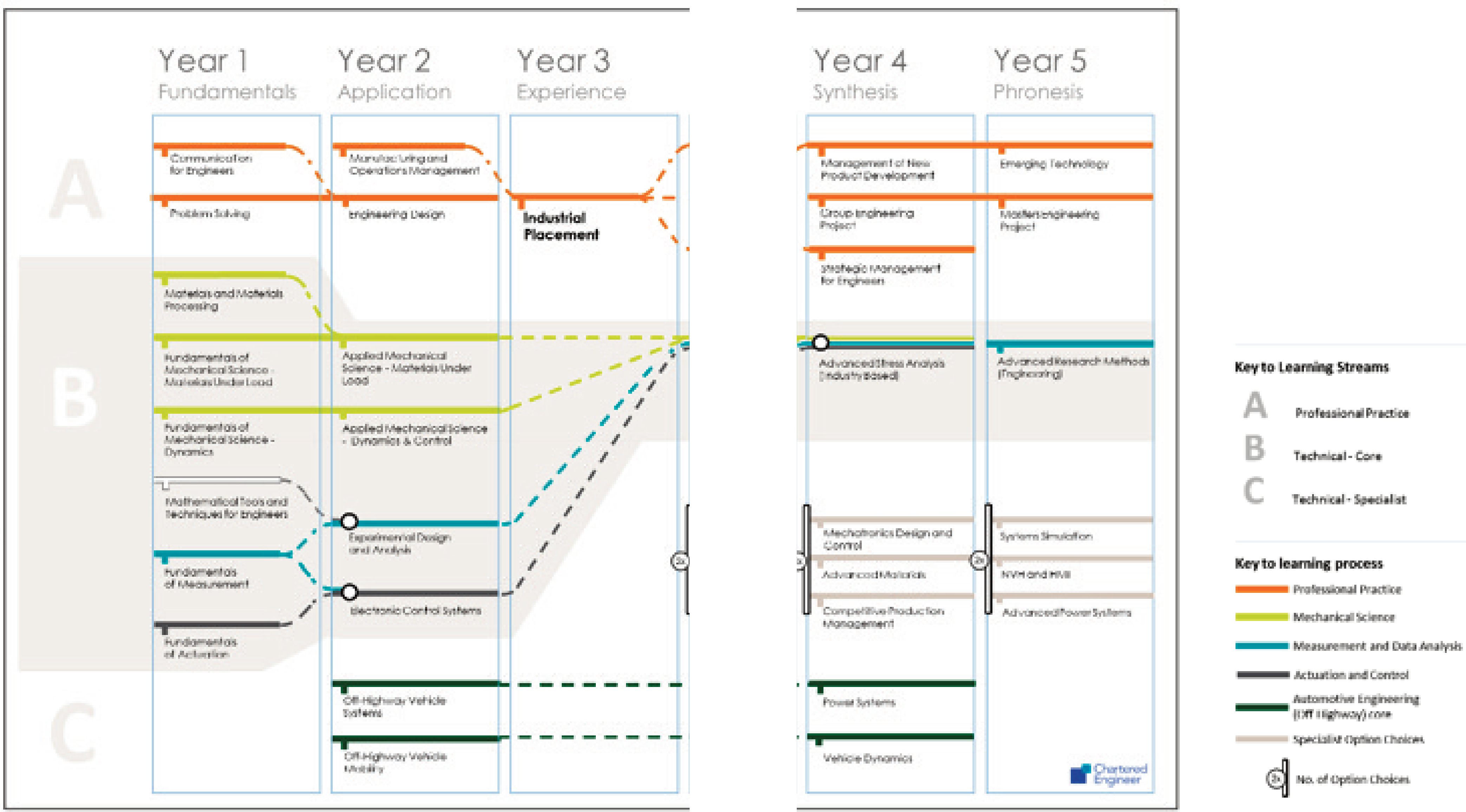

Figure 8. An example of an operational curriculum map.

Difficulty in synthesis

Whenever learning activities are written for ease of delivery, rather than ease of learning, there will be a consequential loss of engagement and difficulties with synthesis. By deconstructing the traditional modules and combining knowledge areas based upon application rather than technology field will built synthesis in to the learning programme. Modules may need to be retained if they are the standard unit of delivery within the institution, however the learning need should be the driving force behind selection of topics, timing, delivery style and assessment method. The learning programme should not be modularised for the ease of module management and workload planning, it should be constructed to maximise learning gain in spite of consequential difficulties with workload administration.

Shelf-life of content

This is of particular importance when considering the learning of 'troublesome knowledge' and 'threshold concepts'[3 8 9]. Threshold concepts are more important than the topics. The topics can and often will become out of date within a predictable period, however the threshold concepts will remain for a lifetime. For example, new developments in project management will produce new design processes during the career lifetime of the graduate so any standard method learned at university will become out-of-date – however the understanding and belief in the benefits of detailed planning, frontloading, and concurrent engineering, being threshold concepts, will remain relevant and will drive learning in the future. As it is understood that threshold concepts have a greater relevance on learning and capability development, it is imperative that the threshold concepts are identified in parallel with the ILOs prior to the design of assessments and the learning plan[10].

Module content is biased to preference of an academic without confirmation of relevance or balance to the programme or future

It is imperative that an effective learning programme is designed holistically, to avoid the content selection biases, and to ensure that the learning content and practices have a valued contribution to the course, e.g. constructive alignment model[4]. A top-down, pull-centric, process-based course programme, by its very nature, identifies course content, content learning timing, and weighting at a course level. If the course programme is written so that content and delivery is appropriate to the needs of the outcome capability, it cannot then be influenced by personal biases. Further, this also ensures that contemporary topics of an unfamiliar nature which are recent requirements will be included and that more traditional material is included if required and replaced if not.

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An Engineering Renaissance

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Introduction

The Engineering and Technology Skills and Demand in Industry report 2016 should be a wake-up call for engineering educators. This is not the first time the alarm has been raised by employers both in the UK and in many other countries, including Canada and the United States.

This same message is repeated time and time again by employers, both empirically and anecdotally, yet progress remains sluggish at best. Engineering educators cannot continue to simply hit 'snooze' and hope the problem will go away.

In the simplest terms, at the root of the problem is a system of undergraduate engineering education that's designed primarily around the needs of 4% of students. Only four out of every 100 students in the UK enrolling in engineering degree programmes go on to undertake a PhD. It's unsurprising that a system created with the intention of preparing young minds for advanced research is ill-suited to the expectations of the remaining 96% of students.

Engineering educators need to radically rethink the learning experience for students. This isn't something that can be fixed by tinkering around the edges of the curriculum or simply introducing more internships.

A more fundamental rethink is overdue. We need to flip engineering education from being a pursuit focused around the 4%, to one that's primarily designed around 96% students who are seeking careers outside academia.

Engineering education should focus on serving its primary constituents:

Students: offering a fulfilling, relevant and stimulating learning experience that prepares them for the employment market.

Employers: developing students with the skills and the mindset to meet the needs of organizations.

Economy: producing diverse talented 'doers' who will create jobs that don't yet exist and drive sustainable growth that generates prosperity while protecting our society and preserving our resources.

This is not a zero sum game. We can still provide ample opportunities for the 4% seeking an academic career, and indeed for every undergraduate to understand the value and impact of research. As engineering educators we must shift our focus to our primary constituents - students, employers and the national economy - and create new models designed around their needs.

Section A: What's Wrong

1. Theoretical Content

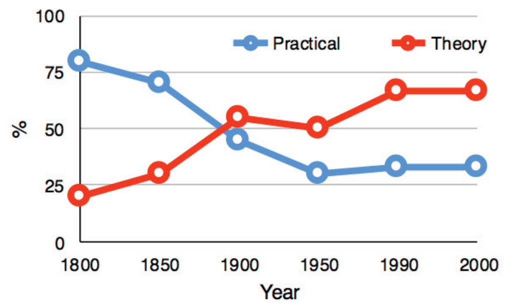

Figure 1. Trend of the Engineering Education over the Years: Practical versus Theory (adapted [6])

This revealing chart in Figure 1 is taken from a report on the Evolution of American Engineering Education produced for the 2015 Conference for Industry and Education Collaboration. If Canadian or British educators were to plot similar data, the result would likely be very similar.

If we agree that engineering is a process – rather than simply a body of knowledge dominated by mathematics and science – then this chart suggests that the education system has lost touch with the roots of a profession where theory and practice should go hand-in-hand.

Even a cursory review of the typical undergraduate engineering courses that a student must complete reveals an experience that's focused almost exclusively on abstract concepts and theory without context or real-world application.

"We don't have, from our point of view, the right approach to educate our young engineers. Students in university or college learn all the technical basics from a theoretical point of view, but they don't really focus on the practical implementation of those learned skills into the real world. It's frustrating for the students, but it's also frustrating for us. When young people come into our company, they have a lot of new, creative ideas. It's really refreshing to see it. What they lack is the ability to implement them in a company environment," quotes Robert Hardt, CEO of Siemens Canada[3].

We have reduced engineering education to a production line where students undertake courses as if they were on a conveyor belt – or more accurately a fast treadmill – where theoretical knowledge is poured-in and then simply regurgitated in what seems like an endless round of testing.

2. Outdated Learning Model

Before we explore the latest teaching and learning methodologies that are being continuously developed by educators across the world, we need to acknowledge a simple truth: lectures don't work.

Even in this image (Figure 2) from 1350, one can still see that the students are not concentrating and are talking to one another during the lecture. The notion that young people can best understand concepts by passively listening to a professor imparting knowledge must be refuted once and for all.

Figure 2. Illustration from a fourteenth-century manuscript shows Henry of Germany delivering a lecture to university students in Bologna. Artist: Laurentius de Voltolina; Liber ethicorum des Henricus de Alemannia; Kupferstichkabinett SMPK, Berlin/Staatliche Museen Preussiischer Kulturbesitz, Min. 1233

"More than 700 studies have confirmed that lectures are less effective than a wide range of methods for achieving almost every educational goal you can think of. Even for the straightforward objective of transmitting factual information, they are no better than a host of alternatives, including private reading. Moreover, lectures inspire students less than other methods, and lead to less study afterwards." 'Lectures don't work, but we keep using them'.[2]

As engineering education has expanded, the reflex of universities seeking to increase student numbers has been to simply add more 'bums on seats' in the lecture hall.

The lecture model that's still pervasive, particularly in the crucial early stages of an engineering degree, reduces the learning experience to a dissemination of knowledge where a student passively ingests information. Students then undertake assignments away from the classroom, often struggling alone or seeking quick fixes to pass tests by cramming or taking shortcuts.

We don't have lectures in secondary schools so why should we have them in universities?

3. 'Survival of the Fittest' Culture

While most engineering educators would no longer dare to utter the admonition: 'look to your right, look to your left, only one of you will be here next semester' on the first day of classes, the 'survival of the fittest' culture remains endemic in engineering schools.

The experience of engineering students is dominated by an overwhelming battery of testing and measurement. This inevitably leads to a culture of competition and comparison, rather than collaboration and cooperation.

While many engineering educators have sought to emphasize the need for group projects, these cannot flourish in an atmosphere of competition where sharing is viewed with suspicion and where the emphasis remains on competing against one another.

"Most young women — and lots of men, as well — don't want to be in an environment where you are constantly expected to prove that you are better than other people. They are much more comfortable in an environment where everyone works together to make everyone more successful. By contrast, the testosterone culture is highly competitive

with lots of bragging and lots of ridicule if you don't know something that someone thinks everyone should know. The mindset is that we're all here to show how smart we are and how much better we are than everyone else. It's not a good environment for most people," quotes Maria Klawe, President, Harvey Mudd College.[5]

With a rigid curriculum and a predefined path to graduation, too many students feel disempowered and simply adapt to survive by learning to pass tests, not learning concepts or developing meaningful skills.

The high dropout rates should be regarded as a failure of educators, and not of students. Even for those who make it through, many suffer unnecessary stress and anxiety imposed by this regimen.

The result is that some of the best, most creative engineers – including many female students – feel alienated by this culture of competition and scoring. This doesn't prepare them for the real world of engineering and conversely it 'weeds out' some of the best talent out there.

4. Inadequate Partnerships with Schools and Employers

Figure 3. Representation of Partnerships with Schools and Employers

Too often there is a sense of complacency among universities, which often point to their partnerships with industry as evidence of flourishing relationships between academia and business. These institutional connections, while valuable in supporting research and development in engineering, rarely trickle down to undergraduate students.

The first time a student visits a university will likely be when they are making their selection, if at all. They have very little idea what they are buying at a time when they are making one of the most important and consequential decisions of their young lives.

Unless they have a family member with an engineering degree they'll embark on their degree programme, one that will likely impact the course of the rest of their life, with almost no knowledge of what lies ahead of them both academically and professionally.

Very few engineering graduates can be found teaching in secondary schools, and career advisers will likely have only minimal understanding of the opportunities open to engineering graduates.

Without advocates within the school system, and without an A-Level or equivalent qualification on offer in engineering, very few secondary school students will consider or be encouraged to consider engineering unless they have a family connection or unless they fit the stereotypical personality of a mathematics or physics 'nerd'.

"If we see engineering education in terms of desirable engineering habits of mind as well as subject knowledge and clearly articulate how best these can be taught; and if we offer teachers high-quality professional learning to design new ways of teaching and working with engineers; then we can understand what schools need to do to ensure more students have a high-quality school taste of what it is to be an engineer so that more choose to study engineering beyond school and potentially become engineers," says Bill Lucas, Director of the Centre for Real-World Learning at the University of Winchester.[8]

Too many students are 'flying blind' when they select a degree in engineering.

The first time a student will meet an engineering professor will likely be on their first day of class, and even then they'll likely be stood at the front of an auditorium full of hundreds of students in the same boat.

Similarly, the first time many undergraduate students consider their future career trajectory and begin to contemplate their life after graduation will be in the later stages of their university lives.

Much more needs to be done to break down walls and to build new bridges for the benefit of students and their future employers.

5. Lack of Gender Diversity

"*We are all better off when the people taking decisions are a mixture of women and men. The increasing presence of women in cabinets, in boardrooms and in positions of leadership throughout our society gives us a balanced perspective on the challenges ahead of us. If we can get more women involved in building what are the foundations of our lives - our cities, our health, our infrastructure - we will all benefit.*"[7]

Once bastions of the male elite, professions like medicine, law and architecture have made notable progress on this challenge. A few decades ago, Canadian law schools were largely male. Today, the majority (53%) of law students are female.

The same cannot be said for engineering. Using almost every measure available, the representation and the opportunities for women are unacceptable.

Engineering schools must accept their share of the blame. The enrolment rates for female students remain pitifully low.

In Canada, the share of women in undergraduate enrolments peaked in 2001 at 21%. and declined thereafter to 17.1% in 2008. The figure now stands at 20%. In 2015, the Lassonde School of Engineering launched the 50:50 Challenge to become the first engineering school in Canada to achieve a 50:50 gender balance, and was followed in 2015 by the University of British Columbia, which has pledged to achieve 50% female enrolment by 2020[1].

It's a stubborn problem that's shown a remarkable resistance to efforts by many in academia and the profession to shift the needle. We have seen occasional spikes in female enrolment, but we have failed to translate this into a sustained change over time.

It's finally time to confront the failures of attempts to tackle this disparity. They haven't worked. We cannot go on patting ourselves on the back for the outreach programmes that have been put in place by engineering educators across the globe when these have not delivered results. At the same time, we can't just blame the media for portraying stereotypical imagery of engineers or claim this is a societal issue that's too big to fix.

Engineers, and schools, in particular, need to be prepared to take a long hard look inwards to the prejudices and biases that have remained untouched for too long. They also need to look outwards to organizations that have begun to successfully tackle this issue and to leaders in other professions who began to face up to this problem long ago.

Section B: The Engineering Renaissance

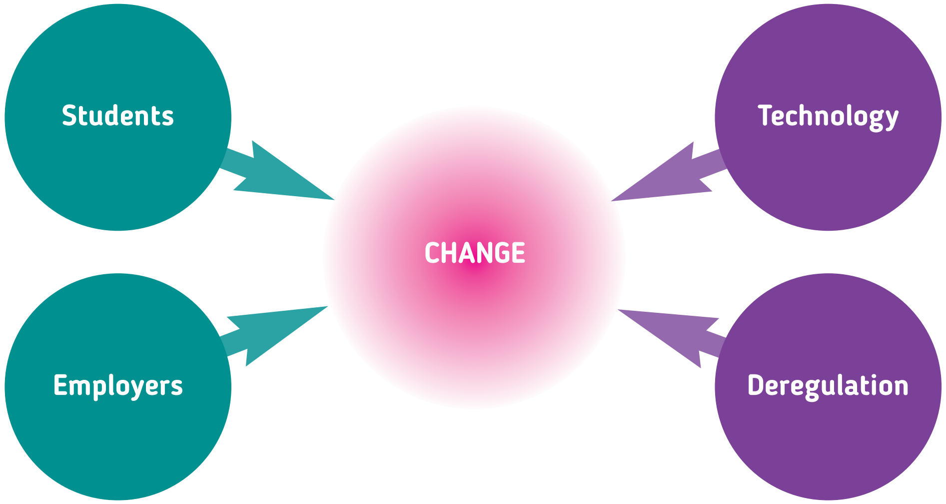

Figure 4. Drivers and Enablers of Change in Engineering Education

The stars are aligned for radical change. This moment offers new opportunities for engineering educators to rethink and redesign the learning experience to better serve the needs of students, employers and the economy as a whole.

Drivers of Change

Students: As students begin to consider a university degree as an economic decision rather than simply a rite of passage for the few, more and more young people will expect to see a return on their investment by acquiring relevant skills and real-world experience during their undergraduate studies.

Employers: As the IET Report demonstrates, employers are increasingly vocal in their dissatisfaction with the current engineering education system. For some, this will translate into a greater commitment to working in partnership with higher education institutions, while for others it'll mean creating their own training programmes for school leavers, or even establishing their own universities to offer more options for budding engineers.

Enablers of Change

Technology: Numerous industries are facing the prospect of digital disruption, and higher education in engineering is no different. This will enable many new entrants into the marketplace offering online learning and blended models of online and face-to-face instruction, while at the same time freeing up more universities to 'flip' their classrooms to focus more on 'learning by doing' supplemented by digital content.

Deregulation: The UK's new Higher Education and Research Bill (2017) offers the prospect of a new generation of engineering schools to enter the marketplace offering more choice for students, more variety in the sector and more opportunity for experimentation in delivering new kinds of learning for engineers.

For a rebirth, or Renaissance, to take place in any part of society the underlying conditions must be conducive to drive and enable change.

However, radical change doesn't happen automatically. It takes a group of people with a common cause come together to seize the moment to create new organizations, new models of delivery, and new approaches within existing institutions.

Section C: What's Needed

1. Relevant Content

The efforts to adjust the curriculum content to better meet the needs of students and employers tend to be add-ons or complementary to the core theory that remains the focal point of the learning experience - as the diagram (Figure 5) below displays.

Figure 5. Representation of Complementary Courses offered in Engineering Degrees

There is little purpose in adding an ethics course, and then assume that engineering graduates can apply that learning to their decision-making. Similarly, you can't simply add a class on entrepreneurship and expect students to adopt this mindset unless this spirit runs throughout the whole educational experience.

The "Capstone projects" at the very end of an engineering degree do not make engineering graduates suddenly able to apply all the abstract theory they've been deluged with over the previous three and a half years. Learning and practical applications should be integrated at every stage of learning.

There's also a danger by adding more and more courses in an effort to adapt to the needs of employers of making engineering degrees too long and too overwhelming for students. When practical or real world courses are added, theoretical ones are rarely subtracted.

The starting point for a redesign of the learning experience for students, and of the content within that, is to focus on innovation and to build a curriculum around that concept rather seeking to add to an already overloaded set of courses.

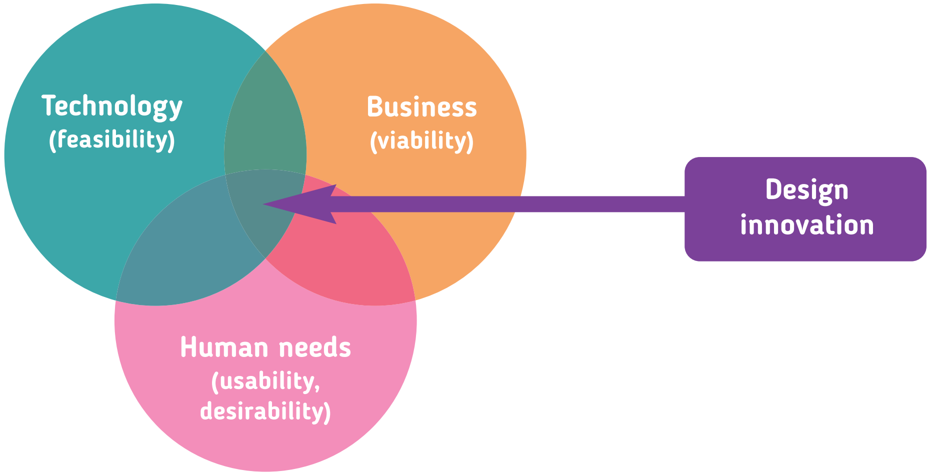

Figure 6. Design Innovation (adapted[4])

We must do more to integrate theory, practical application and context to every course. Rather than add more courses, we can teach calculus through a community engagement project or explain thermodynamics in the context of the global energy market. This isn't just more engaging, it's generally a more effective way to teach concepts.

From this starting point (Figure 6), we can build a learning experience to prepare the engineering graduates that employers seek and society needs.

However, this focus on innovation alone is insufficient. Engineers need to be more than simply innovators. They need to understand the context in which they are operating and their responsibility to the environment, natural resources and the people of this planet.

We live in an ever more complex, interconnected and interdependent world.

Whether it's energy, transportation, infrastructure, urban redevelopment or any challenge we face, we must increasingly view these through the prism of multiple lenses (see Figure 7).

The Fourth Industrial Revolution, a term coined by the World Economic Forum, promises to bring even greater complexity to issues faced by engineers as we see the convergence of digital technology with physical systems and biological processes. The rapid development of artificial intelligence, hyper-connectivity, and widespread automation will give rise to new challenges where engineers must act as leaders with empathy, not simply acting as implementers of technological change.

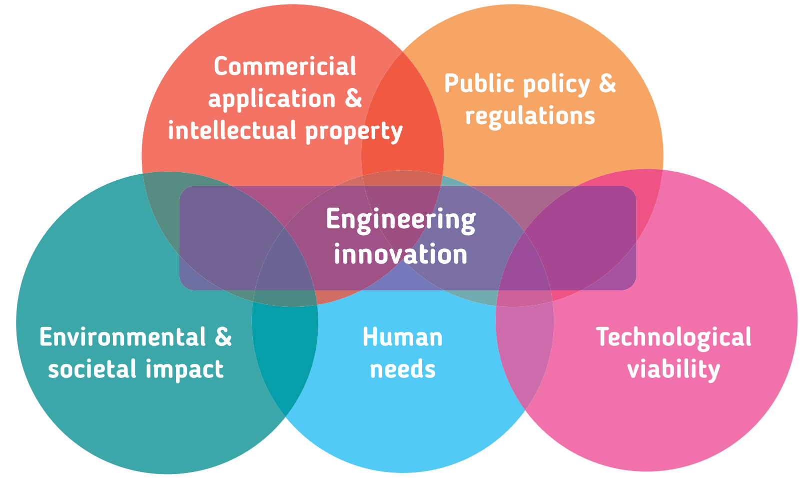

Figure 7. Representation of the Multiple Lenses of Engineering Innovation

2. Collaborative Culture

Even if we can transform the content of the learning experience, without a shift in the culture, we'll not make the progress that's desperately needed.

At the heart of the change that's needed is a definitive shift away from measurement and testing. This breeds a fear of failure, produces excessive stress and anxiety, and underpins a competitive environment. We must build a culture of collaboration and move away from the obsession with a constant assessment.

The first opportunity for a very different approach to measurement is the admissions process. Currently, in the UK – as in Canada – the typical decision-making is made on the basis of grades. Engineering Faculties and Schools rarely interview or 'audition' candidates, and admissions are based on a limited set of data. To build a culture that values people, the best place to start is admitting students based on who they are and not what they score.

The learning experience in engineering need not be a barrage of testing and measurement.

Organizations are increasingly seeking graduates with a collaborative approach, a learning mindset, a confidence in communicating, and an ability to interact with a variety of people from different backgrounds. Engineering schools tend to provide quite the opposite environment where the emphasis is on the right answers to questions, rather than asking the right questions.

While there are attempts to integrate more teamwork and group projects in engineering education, these rarely achieve their intentions unless there's a shift away from the reflex to measure. What's required to build a culture of collaboration is a far-reaching re-design of the system that moves away from both measurements.

The starting point for a more collaborative learning experience is to co-create it, rather than impose it. With new schools, there's an opportunity to develop courses and to design learning experiences together with students and employers. With existing institutions, there's the opportunity to prototype one course together as a partnership between academics, students and employers, and then roll this concept out more broadly. This helps to break down hierarchical divides and develops a sense of shared ownership, that's the basis for a collaborative culture.

Instead of a constant stream of testing, we can instead introduce a portfolio approach where students develop their own collection of projects over their education. Such a portfolio can then be presented as the outcome of their time in engineering education rather than a spreadsheet of test scores.

This diagram (Figure 8) below emphasizes the need for self-awareness and reflection throughout the learning journey, moving away from the high-speed treadmill of engineering school that exhausts students leaving them little time or opportunity to reflect on their progress or consider where they wish to explore next.

Perhaps, most radically of all, we should place much more emphasis on making the engineering education fun and fulfilling. Talk to a recent graduate in engineering, and while some will have enjoyed parts of it, few will tell you it was an experience they look back on fondly as a time they fell in love with engineering. For many, unfortunately, it's quite the opposite. Those who studied longer ago should resist the rose-tinted lens of memory and the temptation to impose the same rite of passage on others.

Not every class can be joyful and not every assignment can be stimulating, yet there's no need to sacrifice rigour when we put more problem sets in context and focus less on competing, and more on what we can achieve together. If we do more to make classes engaging and allow students to discover new questions through practical challenges, we can create a more positive, optimistic and happier environment that's more conducive to learning and more inclusive for every type of student.

And there's a silver lining. Happy students who enjoy their engineering education will be the best ambassadors to share their experience with their friends, family and connections. This is far more effective than any marketing campaign or advertisement. They'll also make for engaged alumni who want to stay part of the community with positive memories of their time and who will act as roving advocates to reinforce a positive perception of the university.

3. Flipped Classroom

There's lots of talk about pedagogical innovation, blended learning and flipped classroom models within the education community. We can easily get lost in the various nomenclatures and in disputes about what's a passing fad and what's not.

We should start by accepting that there's no silver bullet or perfect teaching methodology. That doesn't mean we should just sit back and continue with the flawed lecture model, but it also means we don't need to put all our eggs in one basket or impose a methodology across the system. What's key is to be willing and able to experiment and to work collaboratively to develop models suited to a variety of different students who have different backgrounds, different mindsets and different priorities. If we focus only on one approach, we risk limiting ourselves and limiting the types of students who will consider engineering.

It's clear that we need more 'learn by doing', more use of digital content and more opportunities for students to get out of the classroom and apply their understanding to messy real-world problems. What's not clear is the best model or means to deliver that. It's likely there isn't a perfect model out there and nor should we seek to just replicate the most innovative exemplars.

Instead of replicating others, we should learn from the change makers in many different contexts and then work together with students, with employers, and with our own community to develop learning experiences that reflect our own identities and our priorities. What's important is that just as we want our students to be less fearful of failure, we should apply that same mindset

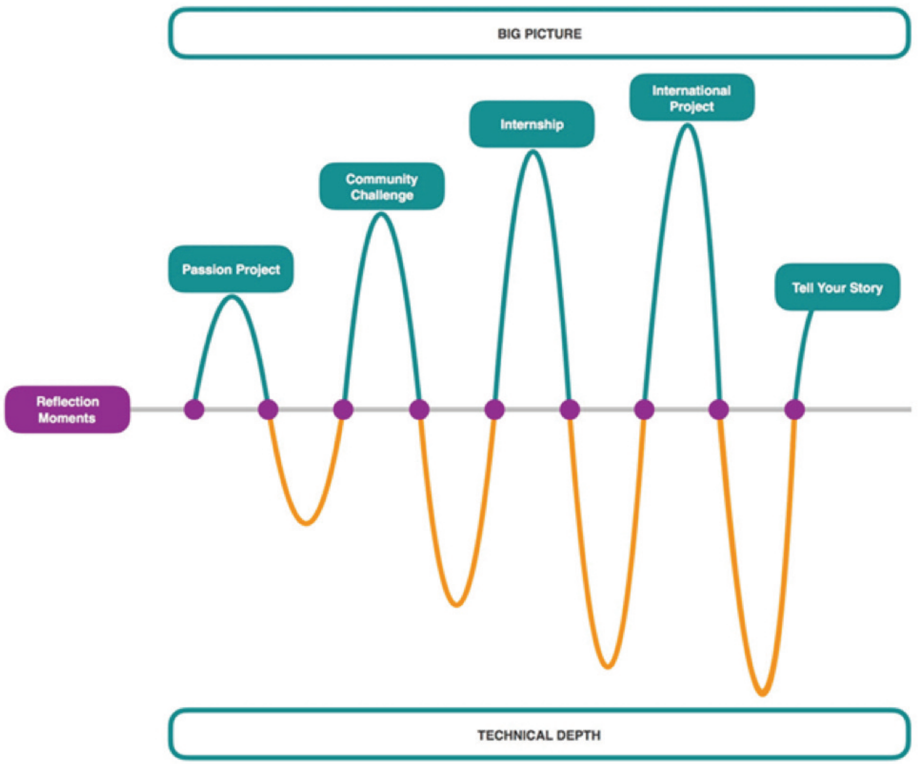

Figure 8: Representation of Sinusoidal Learning Pathway

to ourselves. When we introduce a new learning tool or a teaching model, we shouldn't be dismissive when results do not come overnight or where there are problems identified. We must be more open about what's gone wrong and seek to overcome the challenges, rather than instinctively reverting back to the traditional methods at the first sign of difficulties.

We should experiment with different concepts and celebrate - not denigrate - those who push the envelope and take a risk.

Most importantly of all, as engineering educators, we must place a higher value on teaching throughout our institutions. That's an easy thing to say and a much harder thing to do. Of course, we all know that the academic system is set up in a way that places research at the forefront, and often leaves teaching and teachers at the lower end of the totem pole. That's not going to change overnight yet we shouldn't use it as an excuse for inaction or a reason to walk away from the scale of the challenge.

If we frame the challenge as teaching versus research or the summit as being a time where teaching considered as equally valuable in the academic milieu, then the scale of the challenge will always be too daunting, and it'll be too easy to get bogged down in failed expectations.

Instead, we should accept that we can introduce new incentives to place more emphasis on teaching in the careers of academics and to elevate the value of teaching within academic institutions without getting into a zero-sum game mentality where teaching is always in competition with research. Again, there's a danger in seeking a solution that seeks to change the entire system, and focus on making changes that are relevant and application to each different academic setting. That will drive organic innovation, and move away from the battle between teaching and research that promises to pit ourselves against one another rather than coming together to find different approaches that avoid framing this challenge as a dichotomy.

The key principle that we deployed at the Lassonde School of Engineering in Canada was to invest in people. This sounds obvious, and even trite, yet it's too often neglected in this context. Many universities invest substantial sums in new infrastructure and technology to drive teaching improvements and 'flipped classroom' models. While these investments may aid the process, the most powerful asset can be forgotten: the professor. We need to devote resources and time to give faculty members the opportunity to develop and continuously improve their teaching skills. We should give more freedom for the best teachers to spend more time teaching - and be recognized accordingly and relieving those without a passion for teaching from their classroom responsibilities to focus on research.

4. Integrated Partnerships

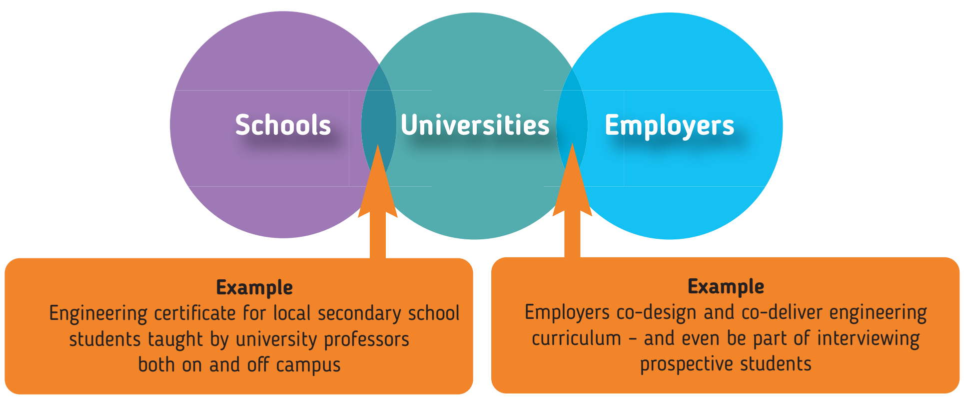

Figure 9. Integrated Partnerships with Schools and Employers

As noted above, there is much more to do to make the transition from school to higher education to employment less of a maze and more of a runway.

We need to build more bridges. We need to break down walls. But that alone is not enough. We need to cross those bridges and be willing to cross those divides (see Figure 9) to make them more and more blurred, and less and less relevant.

While initiatives to increase outreach to schools are to be welcomed, we also need to bring schools to us. We need students, parents, teachers and guidance counsellors to become familiar with engineering education and to spend time in our home, as well as going to theirs.

While summer schools and open days are to be welcomed, we can go further and consider much bolder ideas. Why not offer an "A-Level" equivalent or certificate in engineering to local secondary school students taught on campus by professors? This could be recognized as a pathway into engineering that means math and physics are not required. This won't just make engineering less mysterious, it'll break down the mystique that surrounds academia and universities and can intimidate those who don't come from backgrounds where a degree is the norm.

While more efforts to bring employers and entrepreneurs on to campus are important, we also need to spend more time going to them and understanding what they do and why they need a different type of engineering graduate. There's no point just contemplating this on an abstract level at conferences and seminars. Just as students and schools should spend more time in our homes (Engineering Faculties), we as educators must spend time in the homes (plants, offices, facilities) of employers. Furthermore, we should resist thinking that initiatives like "Entrepreneurs in Residence" or "Employer Roundtables," although worthwhile, will truly address this divide.

We can give employers much more 'skin in the game' if we invite them to be part of selecting students and in co-designing our curricula, rather than just inviting them to give talks.

We should build these bridges, but true success will be making these bridges unnecessary.

5. Co-Designing Diversity

Addressing this seemingly intractable challenge will not be straightforward or achieve immediate results. We must start by recognizing that existing efforts have barely made a dent.

There should be a focus on looking inwards at the culture of engineering schools and whether it offers an environment that supports, inspires and values women.

The reason this challenge is listed fifth on the list is that many of the approaches outlined above - including a more relevant human-centered curriculum and a collaborative culture - will be part of the shift that's needed.

What's needed most of all isn't to reach out to more women or adapt the learning experience that will attract more female applicants - although both are important. What's needed is to bring more women into engineering schools - even if they are not prospective students or engineers themselves. Men need to work alongside women to redesign and co-create a different culture and a different set of values. With a student body that's over 80% male and with a faculty that's even more male dominated, it's unlikely that the people inside engineering schools understand the changes that are needed.

There are many women in industry, in business, in other parts of academia, and in many walks of life who can work together with female engineering students and professors to work with men to identify the changes - both tangible and intangible - that we will begin to make meaningful progress.

New engineering schools cannot be complacent about this challenge either. Unless women are involved in the development of every aspect of the organization and the learning experience, it's unlikely they will generate different results.

Section D: What's Next?

Engineering educators should avoid the temptation to attempt quick fixes or respond reactively to the growing calls for change.

This won't be solved by opening a shiny new 3D printing lab or innovation space, or by adding a new entrepreneurship course, or other similar gestures that have limited impact in addressing the fundamental issues that need to be addressed as outlined in this paper.

At the same time, there's a danger in overthinking this challenge and reaching for an all-encompassing sector-wide solution. We must focus on actions, not just words.

What's needed - we believe - is not a uniform model, but to allow this emerging Renaissance in engineering education to flourish. We must give new entrants to the market and innovators within existing institutions the freedom to experiment with bold ideas that seek to redesign the experience, not just to tinker around the edges. We must value a wide variety of new ways of educating engineers and be willing to embrace a system that offers more choice for students to select different paths that fit their needs and reflect their ambitions, rather than imposing a one-size-fits-all route to becoming an engineer.

We must be willing to learn with humility from our mistakes as well as our successes, and to learn from others in engineering education throughout the world - as well as within the UK - who are facing similar challenges. We need to learn from role models and develop bespoke approaches relevant to each institution and the community it serves.

If we set our educators free to experiment, to prototype and to co-design new models with others we can offer an experience that students will love and employers will value. We should all adopt more of a beta-mindset where we accept that change is the norm and the same goes for what we teach and how we teach. We should be less fearful of working with those who don't typically set foot on university campuses, and certainly not in engineering schools. We need to work more with the local community, with underrepresented groups, and with students themselves to design shared learning experiences. We should not ask them what they want and then seek to deliver it. We should work together with our partners at every stage of the design process and break down the barriers that still exist, whether real or imagined.

Above all, we must be willing to 'grow the pie' together. We need to introduce different models of engineering education as we've outlined in this paper. Overall, we need to increase the numbers of students who go into engineering as a whole. This is not a competition; it's a shared challenge that can benefit existing institutions as well as new entrants. We must share our successes - and our failures, we should not be fearful of efforts by innovators to experiment, and we should move away from the 'arms race' of comparative rankings that too often plagues academia to the detriment of those we should serve: students, employers and our economy as a whole.

The stars are aligned for an Engineering Renaissance here in the UK and throughout the world. We as educators need to seize this moment to work collaboratively with students and employers to co-create a whole new set of models to reflect their needs. In doing so, we can turn a fear of change and flux created by technology and disruption, into a new era of enlightenment for engineering education.

Britain has always been the birthplace of invention and innovation in every industrial revolution - from the steam engine, to the computer, to the internet. Now we must unleash engineering educators in this country to shake up the status quo and rethink what it means to prepare an engineer for a world where technology and people can work together to build a more sustainable, more unified, and more hopeful society.

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‘Engineering’ or ‘*The* Engineer’? A paradox of professionalism

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Summary

In considering the question ‘*How do we attract sufficient students into engineering to meet the needs of an increasingly demanding society?*’, this paper delves into what may be conceptualised as a somewhat unspoken paradox faced by contemporary engineering education; the question of whether, in a well-meaning attempt to encourage students to become professional engineers, we are losing sight of the fact that engineering is by its very nature complex and multifaceted. This paper asks whether, in the pursuance of the highly prized ‘Professional Body Accredited Status’ engineering education has lost its way, prioritising ‘The Professional Engineer’ over the ‘Art, Science and Practice of Engineering’.

Introduction

The expectation that formal engineering education will provide young engineers with a broad range of engineering related technical skills, knowhow and understanding represents a universal driver, influencing curriculum development and pedagogic practice globally[1]. Yet despite years of academic, professional body and government initiatives and debate[2 3], the two subject areas where students are most likely to either fail or simply quit their studies are Computer Science and ‘Engineering and Technology’, with attrition rates reported in the UK media at 11% and 8.3% respectively[4]. The reasons behind such poor retention remain somewhat ambiguous, particularly given the fact that both areas are attractive from an employability perspective, in that both report high levels of skills shortages and difficulties in filling vacancies.

In seeking to identify the root cause of the problem, this short paper takes a critical look at student and employer perspectives asking whether the much sought after ‘Professional Body Accredited Status’ has resulted in a professionalised conceptualisation of engineering which is somewhat removed from the realities of practice and which is unhelpful in developing engineering talent for the current and future needs of the world.

Context

As we move further into the 21st century, engineers are often looked upon as being ‘society’s problem solvers’ and, as such, find themselves taxed with finding solutions to a range of global and local challenges. These vary in nature from looking at ways of dealing with large-scale international poverty to finding solutions for environmental issues including water shortages and pollution[5 6]. Defining engineering as playing a vital link between science and society[7], this paper takes a positive perspective of what it means to be an engineer. In doing so it draws upon a number of previous studies by the paper authors to provide a brief critique of the role of the professional engineer within a forward thinking and sustainable ideology.

Conceptual Framework

The role played by engineers within industry and society needs to be a key driver in shaping how young engineers are taught at university level. Despite this key fact, relationships between the education sector and industry / employers are often ad hoc in nature, built on tenuous and opportunistic working relationships in which differing professional viewpoints try to focus on a common, yet poorly articulated goal. In an attempt to provide a more balanced perspective, the two paper authors developed an approach to engineering education embedded within the interchange between professionalism, practice and education. Figure 1 below depicts this interchange providing a visual representation of the area of overlap in which employers, educators and professional bodies must work together to provide a cohesive and relevant education.

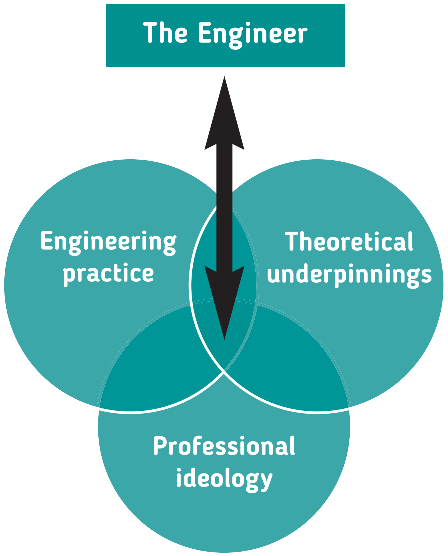


Figure 1: The Engineer - A Professional Practitioner

Methodology

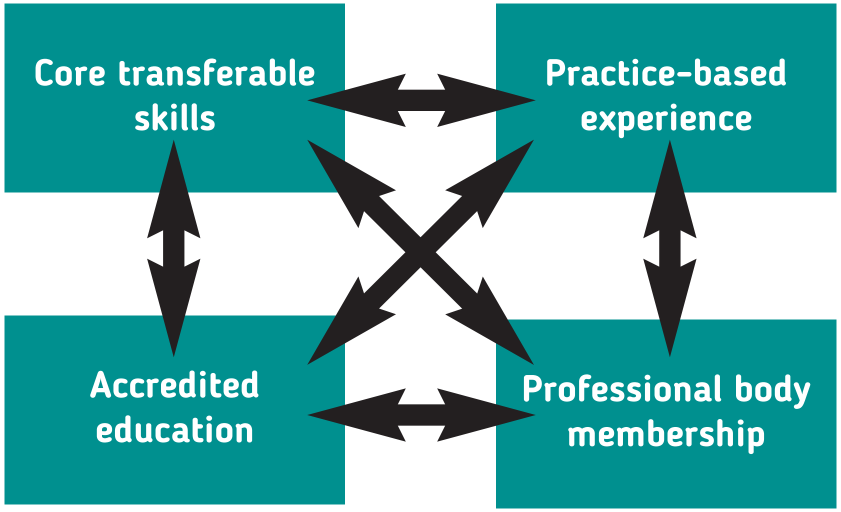
Grounded in the expectation that engineering education will provide industry with work-ready engineering graduates able to meet the challenges of the 21st Century[8], a research study aimed at analysing both employer and student perspectives was conducted. The first stage of the study involved a meta-analysis of research conducted by the paper authors over the preceding five years engaging with a range of employers. This analysis resulted in four distinctive areas for future work being identified. These are explored in the next section.

The second phase of the study entailed the administration of a survey which aimed to examine undergraduate perceptions of how engineering and applied science programmes prepare students for employment. The findings from this part of the study are published in detail elsewhere but referred to in this paper[9 10].

Emergent Findings – Study Stage 1

The meta-analysis of previous work suggests that in order to meet the continually changing demands of modern-day industry and contemporary society, successful engineers need to situate themselves in the interchange between theory, practice and professionalism. The model below, developed out of the emergent study findings, suggests how this may be achieved.

Figure 2: Features of an Professional Engineering Practitioner



1. **Accredited Education:** The role played by engineering education in developing a professional practitioner should not be underestimated. This role varies in nature and captures a range of full and part-time engineering programmes from relatively basic technical training, through to apprenticeships, higher apprenticeships, technician training and degree level education.
2. **Practice Based Experience:** The study findings thus far point to the value of practice-based experience throughout an engineers' career. Whilst at a university level such experience is best gained by participation in a professional work placement, this is not the only route for early career engineers. Other more practice based training programmes, including formal apprenticeships and on-the-job training also have a role to play. Following graduation experience is closely aligned to employment.
3. **Core Transferable Skills:** For universities one widely recognized issue relates to the need to train engineers to solve problems which have yet to arise in industries that don't yet exist. This makes the need for core transferable skills to encapsulate more than hard engineering competencies essential. These requirements include softer individual skills such as flexibility, the ability to communicate across disciplines and at all levels, and a self-determined drive for learning and professional development. Although for the most part common across

sectors, there are differences and the need for review over time in order to remain current and effective.

4. **Professional Body Recognition:** For the established engineer, professional body membership incorporates both peer and professional recognition, providing a distinctive status that is both meritorious and internationally distinguishable. Judged and affirmed by professional peers, recognition at institute level (i.e. Chartered Engineer status) is not easy to achieve and necessitates high levels of individual expertise, theoretical knowledge and professional practice.

Figure 2 depicts the inter-related nature of each of the four features of the model, suggesting that each feature contributes to the development of the other three in some way. This feedback and feedforward is essential if engineering education is to develop in such a way as to ensure the continued academic validity and professional relevance of what it means to be a professional engineering practitioner.

Emergent Findings – Study Stage 2

An initial analysis of the study findings from the undergraduate survey has found that many students are unprepared for the rigours of university level engineering education. The findings of this stage of the study are discussed in greater length in other working papers9,10 and suggest that most engineering students enter their programmes keen to become engineers with a desire to make a difference to the society in which we live. Unprepared for the shift towards independent learning, many young engineering students struggle with the almost contradictory nature of professional engineering education. Whilst many indicate that they favour traditional 'rote' learning there is also a leaning towards problem-based learning approaches[11 12]. This almost contradictory finding gives an insight into the complexities of what it means to be an engineering professional, whereupon there is a need to memorise and learn difficult theoretical concepts whilst also having the ability to apply those concepts to a range of problems and issues.

Discussion

The apparently diametrically opposed features of the professional engineer seems to have resulted in a stalemate, with educational providers, the professional bodies and industry often at odds with each other. In taking a wider perspective it is clear that there is a dire need for a paradigm shift in how we educate engineers. Such a shift needs to bring together the various perspectives so as to synergise professionalism, practice and performance. In short, engineering education needs to be turned 'on its head!'

The following paragraphs suggest how this might be achieved. Based upon the RVS model of engineering education[13] previously applied within engineering programmes, the key areas of professional practice are addressed in such a way so as to promote successful engineering education at all levels.

1. **Relationships:** Relationships within the professional practitioner context encapsulate high level connectivity between and across individual engineers, educational institutions, professional bodies and industry; beginning with the youngest engineering apprentices and including senior engineers and engineering managers the ability to develop trusting relationships based on recognized professional competencies is key to successful engineering. Communication skills play a prominent part in the professional engineers' portfolio, manifested by the ability to explain complicated theoretical concepts in everyday practitioner based language. On a larger scale, the relationships between educators, professional bodies and industries can at times seem somewhat strained. With different industrial, professional and educational epistemologies placing what may appear to be diametrically opposed expectations on young engineers as they graduate from university and make the transition into work. Looking at engineering as a profession, it is clear that there needs to be a single voice to speak across the various disciplines, promoting a positive picture of engineering as a worthwhile and future-proof career. The UK does not have a 'Chief Engineer', hence there is no one person to develop professional relationships across professional bodies and with government and policy makers. This in itself places engineering at a disadvantage, making the need for positive relationships within the discipline itself of dire importance.

2. **Variety:** Within the professional practitioner context of engineering, the concept of variety reflects the range of different disciplines brought together under the wider "Engineering" umbrella. The UK Engineering Council lists 70 different Engineering Professional Bodies14 each one of which has its own professional standards with relation to practice. Looking at such a diverse range of professional indicators encapsulated by professional body requirements, the question of how engineering educators can even begin to prepare future engineers for the unknown rigours of future society when there is little agreement about exactly what skills and competencies are required needs to be asked. Thus, in preparing students to work in industries that have yet to be launched and solve problems that are not yet created it is essential that engineering education produces highly flexible, well rounded young engineers. To do this a range of innovative and academically valid pedagogic practices need to be adopted. Variety in learning and teaching represents a key element of such practice. Whilst the Professional Bodies and industry have a vital role to play in this, the complexities of engineering pedagogic practice mean the primary responsibility for curriculum development and delivery falls to the education sector. Yet educators should not see themselves as the sole 'guardians' of engineering education. Variety in the classroom needs to be translated across the curriculum, with innovative pedagogies including real-life learning opportunities provided by industry and accredited by the professional bodies in such a way that students are provided with the opportunity to gain global competencies.[14]

3. **Synergy:** The need for a synergetic approach to engineering education reaches far beyond the classroom and laboratory to include pre-university education, students' graduate destinations (employers and graduate schools), the wider engineering sector and society as a whole. Professional Bodies have a key role to play in the promotion of synergetic education, setting key performance indicators for engineering education and providing engineers with the means by which professional recognition may be used to show internationally recognized standards and competencies in practice. Likewise, industry needs to play its part, providing work-placements for students and inputting into the engineering curriculum. Working together synergetically, educators, industry and professional bodies can make sure that young engineers are equipped to deal with the challenges of the future.

Using the RVS framework to conceptualise the importance of professional bodies, industry and engineering educators working together, it is clear that no single entity is more important than any other when it comes to developing new engineering talent. Engineering faculties often prioritise the requirements of professional bodies over and above other demands. There are numerous reasons for this but the key driver is, without a doubt, professional accreditation. Yet the research briefly referred to in this discussion paper reveals that many young people are totally unprepared for the rigours of a career in engineering when they enter university. Few understand what professional bodies are and, worse still, many have little or no idea what engineering actually is. Until professional bodies, industry and education begin to work together to promote engineering and the role of the engineer in society, little will change.

In suggesting that engineering education needs to be turned 'on its head', we need to ask some difficult questions. Is now the time to start thinking about 'engineering' rather than the 'engineer'? The multiplicity of talents that enable an engineering enterprise to develop and contribute to industry and the wider society need to be acknowledged. The question is how can we do this? It suggests the need for a broader, more flexible approach to engineering education in the first instance. This should encapsulate choice to promote development along a multitude of pathways, the aims being to be to enable the achievement of aspiration alongside the forming of talent that can contribute to the engineering profession in some way.

Perhaps in its simplest form, building on the ideas captured in the 'Habits of Mind' work[16] conducted for the Royal Academy of Engineering will provide a useful starting point. Focused on school children, the freedom to explore is central to the arguments made by the report authors. This has been reinforced in the recently published follow-up work 'Learning to be an engineer.[17] This freedom and flexibility in learning can seem almost eliminated by university level, as learning is guided by numerous checklists of content, skills and competencies captured in learning outcomes. Is this 'fit for purpose' or is change needed? Change will take time and it will require different thinking on the part of educators, industry and professional bodies. It will require a coherency of effort that embraces the idea of flexibility more so than ever before. As educators and academics we need to start this challenging conversation.

Conclusion

This discussion paper starts off by asking whether too much attention is paid to professional bodies. It looks briefly at a small research study before considering how a model of engineering education may be applied to contemporary society.

In conclusion, there is clearly a need for better working relationships between professional bodies, industry and educators. In Higher Education, the desire for professional accreditation often trumps pedagogic and educational demands, meaning that at times priorities are changed and learning outcomes become unclear. This clearly is not the way forward. Instead there needs to be a mechanism through which different interests can be brought together to promote professionalism and in doing so enable the UK to recruit, train and develop a new generation of engineering talent able to move our society forward.

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The formation of an engineer: A view on the engineering curriculum

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Abstract

The development of professional engineers is a joint endeavour involving schools, colleges and universities and industry. Too often, these bodies have been siloed, influencing a single stage of linear pipeline, rather than being seen as part of a continual process that provides support to potential and professional engineers at all the different stages of their development. In redesigning our education programmes, we considered this broader view and aimed to develop programmes that connect with young people and practicing engineers outside of the traditional cohort. In this paper, we touch on the review process that took place as part of the Integrated Engineering Programme at UCL and give details of how we developed a strand of interconnected activities that forms the backbone of the curriculum across all the engineering departments at UCL.

Introduction

Engineering, as with all the creative arts, requires professionals with a range of skills, knowledge and attributes. What these might be, has been discussed at great length with a procession of reports calling for change in engineering education or levelling criticism at the current process for the development of future engineers. Examples of the well-rehearsed arguments seen include investigations of the 'pipeline' of school leavers into engineering study[1] and particularly the difficulties faced by under-represented groups to enter engineering[2], through to the skills developed during university level education[3]. In addition, the Royal Academy of Engineering produced a pair of reports which looked at the process of "Educating Engineers for the 21st Century" from both the industry perspective[4] and the academic viewpoint[5], highlighting both skills shortages and skills gaps in the graduates being produced.

Similar reports and findings have occurred worldwide. In the US, for example, the National Academy of Engineering[6] called for programmes with a "broader range of interdisciplinary knowledge", while in Australia similar calls have been made in the "Engineers for the Future" report addressing the supply and quality of Australian engineering graduates for the 21st century, published by the Australian Council of Engineering Deans in association with Engineers Australia[7]. In some cases, these reports have acted as a call to arms for educators[8] whereas others have highlighted the shortage of engineers and provided a case, predominantly to government, for increased investment in the education and training of future engineers[9 10].

A recurring theme is a desire for university engineering departments to produce graduates with not only the technical skills of the disciplines, but also with a wider range of transferable skills, an understanding of the societal context of Engineering and in particular an understand of how to transfer these skills into industry. In the US, a significant voice for change in engineering education has been held by Boeing[11]. While, in the UK, the latest IET skills survey gave a stark assessment:

> *There is deeper concern than in previous years around the skills, knowledge and experience of the future workforce – postgraduates, graduates, school leavers and apprentices. One of the biggest challenges appears to be in recruiting candidates with sufficient work experience. Many employers are reporting that the content of engineering and technology degrees does not suit the needs of their organisation because the courses don't develop practical skills or practical work experience.*
>
> IET Skill and Demand in Industry[6]

The call for change seems clear, but what change is required? The Royal Academy of Engineering[5] summed the end goal up as: "University engineering courses must provide students with the range of knowledge and innovative problem-solving skills to work effectively in industry as well as motivating students to become engineers on graduation."

University's role in developing the Professional Engineer

It is generally accepted that university programmes do a pretty good job at imparting knowledge. Skills can be a bit more tricky, while the develop of the attitudes and attributes that industry say they require are the most difficult of all. However, we must also remember that it is not solely the responsibility of higher education institutions to form professional engineers but a joint responsibility of both academia and industry, and a process that should, ideally, be tackled collaboratively and with a timeframe that reflects the trajectory of a graduate engineers career. We suggest that fostering this collaboration is an important conversation, one that has not been fully engaged in thus far, but one that bodies such as the Institute of Engineering and Technology (IET) are exceptionally well placed to facilitate.

We should remember that graduating with an engineering degree is much like passing a driving test. It is not a recognition that the successful individual is an expert driver, but merely that they have reached a sufficient level of competence that allows for the next stage of their development and practice to can be undertaken without strict supervision. Mirroring this, it is vital that we move away from demands for 'oven-ready' graduates and the provision of narrowly focused degree courses, and uphold education as mind-expansion, not training. Together, universities and employers need to embark in a constructive dialog as to what the shared roles and responsibilities are in the formation of professional engineers. Such a collaborative approach is required if we are to attract and keep talented young-people from the broadest range of backgrounds and gender in the profession.

As part of this development, it is the responsibility of the engineering academy and engineering educators to review and analyse the requirements of becoming a professional engineer and adapt their curriculum accordingly. We argue that this is not something that can be done piecemeal, or by one-off, separate or extra-curricula activities, but something of significance that is explicitly embedded into the core curriculum. This does not mean that complete revision is required. It does, however, mean that the whole curriculum must be considered as part of a fundamental review of how each element contributes to the formation of a professional engineer. It should also be the case that we are willing to identify elements that are not best delivered as part of a university programme and that would be better learnt 'on the job', within an apprenticeship, as part of an internship or placement, or after graduation as part of a graduate training scheme.

Need for collaboration: Academia and Industry

Recently at a roundtable event hosted by the IET, leaders amongst the engineering schools across the UK and senior members of Industrial partners, both corporate and enterprise, came together to discuss if the current offering of engineering degree programmes was properly servicing the industry's needs. The main topic of discussion tiptoed around whether or not a wholly interdisciplinary degree that breaks down boundaries between specialist departments and employs the very latest methods in achieving stretching educational outcomes was desirable. However, the conversation tended to lean towards addressing the roles both the HE institutions and industry employers play in contributing to and supporting a graduate's transition between academic study and industry practice. What wasn't discussed but perhaps should be the hot topic of discussion between academia and industry, is the question we pose here "how can the two contribute to and support graduate engineer's life-long learning?"

The MEng or integrated master of engineering science programme, currently offered and accredited across the UK, is recognised as being the basic training required by the Engineering Chartership application process. Following from that, Chartership is only possible once substantial experience is gained and competence is demonstrated. After a student graduates from such a programme, there cannot be the expectation of a fully formed engineer. The only expectation should be that the students have the capacity to further develop in their own professional skills and their understanding of the world of practice, in addition to the areas of engineering thinking, design, analysis and implementation. Education prepares pupils for a life-long career in learning, not just graduation. What is needed is a formal and continuous University-Industry partnership aimed at fostering the future development of graduates as life-long learners, which is driven by creating and supporting relevant and beneficial interactions for all involved.

Currently, much of the emphasis placed by employers during graduate recruitment and graduate training schemes is getting new recruits ready to be integrated into the company, the industry sector and their new working teams. In turn this puts pressure on academic institutions to assist in this endeavor with the aim of improving graduate outcomes and employment statistics. These efforts are often focused on getting the most out of the graduate's first year or two at a company which, as evidenced by the IET report[16], is for many, their first industry work experience. Indeed the years spend after graduation are largely formative, but arguably, it is the years after which will have them making significant contributions to society and creating the most impact. This shouldn't be left up to the industry sector alone. Working partnerships between Universities and Industry, both established and emerging, could support the formation of a life journey via an engineer's daily practice and throughout their career.

Some obvious ways in which this could take form are via alumni/mentoring programmes, CPD opportunities and internships and/or hiring programmes. Beyond those, there could be ways to put into practice a 'pay-it forward' initiative, aimed at informing future cohorts within a range of levels, of the changes in the workplace and industry practices as well as continuous learning opportunities. This could help break down the barriers between the two bodies which are currently focused on the hand-off which occurs after graduation.

Progress so far: The Integrated Engineering Programme

The Integrated Engineering Programme at UCL, better known as the IEP, is not a distinct programme so much as it is a teaching philosophy. Its key aim, is to give students across the faculty, regardless within which discipline they've been inducted, an abundance of opportunities to put into practice their core technical knowledge and develop their own 'transferable' skill sets. Authentic and research-based learning practices have been embedded in each of the departmental BEng and MEng degree offerings. It makes use of active learning techniques, such as problem-based learning, which are rich in real-world context and complexity, to consider such things as stakeholder needs, design, ethics, risk, environment, costs, timelines, estimation and decision making. Those dedicated to IEP teaching, make considerable efforts to create authentic assessments which reflect work commonly expected of graduate employees and/or are set out and assessed by Industry partners. Additional elements of the IEP including: an applied teaching and learning approach of fundamental mathematics for engineers; curriculum dedicated to skills-based teaching and learning; and an effort to support the student's own self-awareness of personal strengths, weaknesses, values, own working and leadership styles etc., all have aims to facilitate each student in their individual learning journey towards graduation and beyond.

The IEP created time and space in the curriculum for students from all departments within the Faculty to participate in nine distinct, diverse and technically challenging projects before the third year of their chosen programme. Whether classified as a Challenge or a Scenario[13], each project provides students with an opportunity to consider a new set of stakeholders whilst working: with a new academic lead and often industrial client(s)/advisor(s), amongst a new student team, towards a new timeline with new deadlines, within new learning environments and to submit or present new project deliverables. Evaluation reports from the ninth and final two-week intensive, inter-disciplinary project called How to Change the World, which has student teams tackle socially driven 'wicked' problems (www.ucl.ac.uk/steapp/how-to-change-the-world), have highlighted the ability of students on the IEP to pull their team together and start projects off proficiently and resourcefully. This, partnered with new remarks by academic leads and external third party partners, that student solutions provided at the end of the two weeks have also been improving in terms of technical feasibility, social desirability and costing considerations, are just a few observations which suggest that elements of the IEP can help students translate their engineering education into the day-to-day work of engineering.

Another distinction of the IEP is the embedding of a 'Minor' within the departmental BEng/MEng degree programmes. Much like a pedagogic framework often associated with North American undergraduate degree programmes, the IEP Minor comprises one-eighth of the second year and one-quarter of the year three studies for all students within the IEP. The aim of the IEP Minor is to offer the students an opportunity to dedicate their elective/optional modules and enable in-depth of study in an associate area which is either linked to industry sectors (i.e. nanotechnology, sustainable building design or crime & security engineering etc.) or is skills based (i.e. programming, management or foreign languages etc.). An additional founding principle of the IEP Minor is that it must be offered to students from more than one discipline, thus making it interdisciplinary in nature. Recently, an event was held bringing together industrial partners and graduate employers with IEP students to discuss the career pathways aligned with their chosen IEP Minors. A comment after the event from one of the attending industrial partners reflected an intention set out by the IEP, which was to align curriculum with industry sectors both traditional and non-tradition to the disciplines offered at UCL.

> *You may find that the majority of your students will find future employment aligned with their 'minor' rather than their chosen field of engineering"*
>
> Sinisa Stankovic, Rapiere Software Ltd. (2017)

It is recognised, by all associated with the IEP, that authentic learning (including PBL), enquiry-based learning and skills-based learning are all suitable, and often successful, ways of providing students opportunities within the curriculum to develop practical skills. Equally, however, it is acknowledged by many that these can only go so far. Direct industry engagement and work experience is arguably the best approach and the IEP is actively aiming to further advance our curriculum and industry based services to bring opportunities for interaction to the fore. Investigation into how best to position work-placements so that all IEP students graduate with work experience are ongoing. We are also exploring how we can work with our graduate employers to improve their graduate training programmes to align with skills-based pedagogies and developmental activities of the IEP. At UCL Engineering, a team of staff designated to student careers and employability currently sit at faculty level with academic staff appointed within departments to lead efforts in career guidance, internships and student recruitment. These are often the people who do the most to bring industry onto the campus and supporting the students within the curriculum. There is a common strategy amongst all to increase the amount of interaction and influence on the students while they are visiting. This often takes to the form of paired engagement activities like talks on CV writing, assessment centre support or work-place culture with assessment of project work or presentations. A concerted effort towards the development of key relationships with new alumni is also a new strategy for the IEP which is hoped to help pay-it-forward and inform students throughout the IEP of employer expectations of graduate employees, but also provide information on the level of support available to develop individual capacity for becoming a professional engineer

Summary

In this paper, we have outlined our vision for a new model of engineering education that balances the traditional demands for a broad, discipline-based education with the integration of professional engineering skills. We argue that the formation of a professional engineer is a joint endeavour between academia and industry which requires continued collaboration and cooperation, throughout the degree programme and through into the work-place. To effectively do this, the degree level curriculum of engineering programmes needs to be overhauled, so that room is made for authentic learning experiences that allow students to integrate their academic learning with relevant practice in collaboration with industry.

As an example of how this might be done, we share our experience of developing the Integration Engineering Programme (IEP), a framework that is shared across all engineering programmes at UCL which aims to integrate theory and practice lead activities with research-based and industry-led opportunities. Although, with regards to industry interaction, this programme is still a work in progress, we believe that the framework provides a range of opportunities for direct industry interaction which can be exploited in the coming years to provide a fundamental shift in the experience received by our graduates.

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AIMLED – A new approach to engineering higher education

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Problem

The UK needs more good engineers – qualified at all levels. By the 2020's, at least a doubling of HE graduate engineers is required for sustainable economic growth.

Despite huge effort in promoting engineering in schools over many years – (the RAEng reports over 600 current initiatives[1]), no significant increase has resulted in the relative popularity of engineering overall in HE applications. Why is this?

First, there is evidence that problems lie in the perceptions of engineering held by the public – perceptions of manual, trade, low status activities that are reinforced by the media, and those in Whitehall and Westminster. Such perceptions are inaccurate and ill-conceived, yet will be in the minds of many parents, families and teachers of young people, greatly influencing career choice.

Next, youngsters are put off engineering degrees because they believe they are simply 'more maths, more science' – which they often are, presenting curricula incorrectly stressing engineering as applied science. Also A/Level Physics and Maths (two subjects traditionally required for entry to UK University Engineering programmes) struggle to increase numbers. Most recently, c30,000 students annually presented Physics and Maths A/Levels, (a number set to reduce severely, reflecting demographic decline). With c23,000 UK students entering engineering courses, clearly insufficient headroom exists for a doubling of graduates, given other academic subjects' demand for this A/L combination.

The problem is particularly acute in the case of female students, who represented 55.6%[2] of all HE accepted students in 2014/15, yet just 15.1% of those studying engineering. This is despite the initiatives of WISE (Women in Science & Engineering), and the Women's Engineering Society (WES). Here, perceptions weigh more heavily than with male students, and the fact that a significant proportion of Girls' schools do not teach Physics at A/L is a further barrier to considering studying engineering.

Another problem relates to the quality of students recruited to engineering HE programmes. An RAEng[3] study showed that whilst pre-1992 universities are mostly full with well-qualified entrants (obtaining up to 600 tariff points), post-1992 institutions mostly attract students towards the bottom of the qualifications spectrum, achieving their target admissions through Clearing. Inevitably this leads to high withdrawal rates amongst low-achieving entrants.

The problem facing the quest for increasing the number of graduate level engineers in the UK thus appears to be intractable – not enough quality school children are taking A/L Physics and Maths, and seem unable to respond (possibly through problems of engineering perceptions) to outreach and intervention activities.

The waters are muddied by facts emerging from a 2015 Oxford University report[4]. Despite employers' claims that there are insufficient graduate engineers entering the employment market, the evidence is that the fraction of graduates from particular engineering disciplines entering their corresponding industry sector (particularly within manufacturing) is generally <50%, (in some cases, <10%), challenging arguments suggesting substantial shortages of engineering graduates.

This apparent contradiction – the need for a doubling of engineering graduates, yet evidence of lack of employment of existing graduates, is worthy of examination. Amongst possible answers (perhaps cherry-picking by employers, who only choose those with first-class degrees), there are two other important possibilities. Having endured their undergraduate programme, some graduates are put off engineering, seeking employment elsewhere. Somehow the programme did not satisfy what they believed to be an engineering education. Also employers find the skills and attributes offered by students do not represent those expected of a graduate engineer[5] – in other words, the HE degree programme was somehow lacking.

In recent times many people, organisations, and institutions worldwide have been drawn inexorably to the conclusion that something is wrong with engineering higher education, and are doing something about it[6].

Solution

NMiTE is one such institution, currently developing an Accelerated Integrated Masters Liberal Engineering Degree (AIMLED) to correct the situation.

AIMLED results from disruptive interventions to create a new style of engineering programme design, drawing inspiration from worldwide developments that seek to provide more appropriate 21st century approaches to engineering higher education.

Traditional engineering courses build upon bedrock of science and mathematics, viewed as part of a 'continuum' leading into engineering topics. Indeed, engineering degree courses are often presented as 'applied science' – that 'turn science and maths into reality'. This is far from the reality of the relationship.

Science is about achieving understanding of our world by producing models of observed behaviour, which are used to predict behaviours of other possibly more complex phenomena (the 'Scientific Method'). Mathematics has an important role in this modelling activity.

Science is about analysis. Engineering, however, is about synthesis. It is about creating things - products that address and solve the problems, challenges or needs of society. Seldom do these products arise from new scientific and mathematical developments (although there are exceptions); in fact, many scientific and mathematical developments follow engineering creativity. Thus, the science of Thermodynamics came after the creation of early steam engines; the science of Aerodynamics mostly followed the Wright brother's empirical work on practical flying machines.

The 'continuum' between science and mathematics to Engineering is in fact in the reverse direction since engineering creativity often gives rise to developments in science and mathematics. Progress in semiconductor physics (for microchips) and development of the mathematical Fast Fourier Transform used in signal processing are particular examples.

Despite this, many traditional engineering courses are arranged around a 'linear curriculum' that first teaches science and mathematics and then moves to engineering. Analysis dominates in this approach, usually at the expense of one most important example of the essence of engineering - Creativity.

Sir Ken Robinson[7] defines creativity as 'having ideas of value'. Checking such ideas for feasibility, viability and desirability is often described as 'proof of concept', possibly leading to a patentable invention. But bringing ideas to market, to reality, is referred to as Innovation.

Innovation is a process that calls upon a wide variety of subjects beyond science and mathematics. This includes finance, economics, management, quality, IT, languages, rhetoric, marketing, sociology, ethics, art, facilities, human resources – and in particular, Design.

All these subjects (and more) contribute to Innovation, a truly eclectic mix. **The AIMLED programme will make these subjects more visible than conventional approaches, and so will appeal to students with a wider range of backgrounds and experiences.** This will achieve a *'Liberal Engineering'* programme which is *'liberated'* from the strictures and narrow confines of science and mathematics.

Of particular significance is Design – defined by Sir George Cox[8], (past Design Council Chairman) in his 2006 report as: "…*what links Creativity and Innovation. It shapes ideas to become practical and attractive propositions for users or customers. Design may be described as creativity deployed to a specific end.*"

Design goes beyond the 'look' of something (its 'form'). In the context of engineering, Design covers design for form, function, manufacture, operation, reliability, maintenance, and for disposal. Importantly, design is not 'Applied Art', but is a rigorous discipline with its own defined approaches.

So we have the blessed trinity - Creativity, Design and Innovation – the distilled quintessence of Engineering. Yet few HE engineering courses recognise this, instead concentrating on (as described in the US) '*the mind-numbing math-science death march that casts aside thousands of capable young people who might otherwise have made effective engineers*'. NMiTE's AIMLED programme will deal with this through new approaches to curriculum structure and delivery that treats engineering education not as acquisition of a body of knowledge, but as engagement in the Process of Engineering, based on Creativity – Design – Innovation.

The flagship 'exemplifying' qualification for the Engineering Council's UK-SPEC Standard is the MEng. This degree provides the required 'educational base' for formation of Chartered Engineers (CEng). The MEng is an integrated undergraduate Masters level engineering qualification – integrated in that it subsumes a Bachelors level qualification, yet has undergraduate status permitting student loan access.

Under QAA's (Quality Assurance Agency) Course Credit Accumulation and Transfer scheme (CATS), an MEng carries 480 credits, representing 4,800 hours study time. Conventionally these are presented over four academic years, each comprising thirty weeks of 40 study hours. The AIMLED programme presents the degree over three years of 1,600 study hours each, requiring forty 40-hour weeks/year. With inter-block (qv) breaks this will require 46 weeks students' commitment, the remainder of the year being vacation. This accelerated approach brings several advantages - graduates enter employment one year early; accommodation arrangements are simpler and cheaper; longer periods are available for learning and industrial experience (e.g. a third year c20-week industrial placement/internship); and without long vacations, educational momentum is maintained. A 46 week year would allow students to immerse themselves fully in the city, University and, most importantly, in Engineering.

The AIMLED programme

The AIMLED programme material will be presented through four principal themes: *Feeding the World*; *Shaping the Future*; *Living in Harmony*; and *A Healthy Planet*. Aligning with regional and national employment opportunities, these themes also address current global challenges, which will appeal to prospective students.

Theme	Indicative engineering topics
Feeding the World	Agri-tech, food tech, energy, water
Shaping the Future	Advanced manufacturing, maker movement, energy, transport
Living in Harmony	Big data, cybersecurity, smart cities, energy, water
A Healthy Planet	Health, environmental issues, climate change, sustainability, energy, water

Courses will be presented as Blocks of learning lasting for 1 week or multiples of 3 weeks. In alignment with CATS, a standard 3-week Block implies 12 (UK) Credits and 120 hours of study time.

Each Block involves c30 students in groups of five in a problem- or project-based learning format, (projects mainly contributed by industry) with group members having balanced experience/interests backgrounds. A Block will have c35% of liberal (non-technical) content. The Block leader will be an engineer, supported by staff members with non-engineering expertise acting as "peripatetic" supporters of several blocks. A 1-week Rhetoric Block at the start of the degree course will develop reading, writing and presentational skills; subsequent rhetoric elements will be incorporated within all Blocks. Blocks will not usually contain lectures, (except occasional 'enrichment' lectures), but will involve seminars. Knowledge acquisition will be supported via on-line provision, in-house seminars and self-study. Each Block will contain one or two key concepts incorporating a project or problem with a clearly defined outcome (linked across Blocks) and providing evidence for the student's portfolio. A particular strength of this approach is that each Block will integrate contextual liberal study with engineering content and hooks to other Blocks.

The 46-week academic year will typically consist of c14 three-week Blocks and 1 or more one-week Block; some weeks for assimilation and reflection; leaving time for vacations.

On average each 40-hour week will contain:

Indicative general engineering topics	Examples of liberal topics	
Mathematics	Finance	Architecture/facilities
Mechanics	Economics	Human resources
Thermofluids	(Project) management	Health and safety
Measurement	Quality	Diversity
Electronics/circuits	Rhetoric/critical thinking	Environmental issues
Design	Languages	Sustainability
Engineering materials	Marketing	Politics
Signal processing	Sociology	Philosophy
Energy systems/conversion	Ethics	Human interaction
Energy	Art/aesthetics	

- 20 hours of project/3 hours of student-led group tutorials, considering detailed aspects of the project/problem-based learning tasks;
- problem work (comprising groups of five students);
- 2 hours of seminars (comprising 30 students) involving subjects key to addressing the project/problem-based learning tasks;
- 15 hours of self-study, supported via on-line provision.

All third year students will undertake a major project/internship (senior capstone style) with an industrial sponsor. Student exchange schemes, studying abroad and the acquisition of a second (or third) language will be encouraged.

Assessment of knowledge, understanding and competence resulting from each Block will be included. It will be synoptic (not necessarily exam-based), aligned to learning outcomes, and will involve internal and external examiners.

Every student will develop a portfolio of achievements, with most Blocks resulting in a deliverable that can be included.

Admissions

The AIMLED programme is predicated on broadening pathways into studying engineering to increase diversity of intake.

NMiTE's admission processes will identify students who combine high academic ability with grit, curiosity and passion, and the capacity to develop life-long learning skills. NMiTE is keen to inspire women desiring to study engineering and will seek to establish a gender-balanced environment among both staff and students. In this regard, NMiTE is keen to respond to the work of Professor Averil Macdonald.[9]

Using APL/APEL[10] approaches, applications will also be welcomed from a diverse range of full and part-time students from non-traditional academic pathways who have already begun careers, including those that have engaged in apprenticeships, or military service.

Prospective students following traditional academic routes will be required to have passed English, Maths and Science GCSEs and have passed 3 A/Levels (with minimum 2 As & 1B), or equivalent assessment (e.g. International Baccalaureate with 36 points). A/Levels in Maths and Physics will be welcome, but these subjects will not be required since support will be available to students as part of the engineering curriculum. At the core of NMiTE's curriculum design, culture, and ethos is the intent to develop a high quality, safe-to-fail learning environment providing students with understanding, knowledge and experiences that will prepare them for employment. Since NMiTE's objective is to educate students and ensure that they are work ready, in addition to the traditional academic thresholds addressed above, NMiTE will utilise techniques used by employers – competency-based assessment (to identify the understanding, knowledge and skill levels of the candidate) and behavioral interviewing (to assess an individual's potential future performance based on demonstrated past performance. AIMLED will be a demanding, intense programme that requires the best most resilient students available.

NMiTE Academic Staff

The appointment of academic staff committed to a new approach to curriculum structure and delivery, and teaching on a ground-breaking engineering programme, will be critical to the success of the NMiTE's degree offer. With a staff to student ratio of 1:13 a high level of staff engagement with individual students is expected. Academic staff will be members of a single multi-disciplinary Faculty, which will also include industry practitioners where appropriate. Academic staff will not be required to undertake technical research at NMiTE, but will be expected to engage in Scholarship in their subject areas, possibly including pedagogical research and development. They will contribute to the full panoply of Quality Assurance measures to ensure that all aspects of the AIMLED Programme remain relevant, up-to-date and topical. Academic staff, as with students, will be expected to demonstrate a keen interest in technical and liberal aspects of engineering and so practice what they preach.

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10 APL – Accreditation of Prior Learning; APEL – Accreditation of Prior Experiential Learning.

From creativity and ingenuity through technology and invention to product and market: a new paradigm for engineering education

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Abstract

Electronics education needs to change to meet the working needs of employers, and to expand by increasing undergraduate student numbers to help meet the shortage of engineers in the UK and elsewhere. In addition, it needs to acknowledge and provide skills guidance and experience for students in the working needs of employers specifically by making group working along with clear verbal and written communication skills the working norm, while the key role of creativity in the engineering design process is developed. Such changes are non-trivial in the context of existing programmes. The decision by Royal Holloway, University of London, to set up a department of Electronic Engineering from scratch (admitting its first undergraduate students in September 2017), provides a unique opportunity to design from scratch a purpose-built facility, and a curriculum that focusses on fostering creativity, group working and excellent verbal and written communication skills throughout the programme.

Introduction

Electronic engineering underpins many of today's systems that we rely on in everyday life including domestic systems, lighting, environmental control, radio and television, music and gaming entertainment systems, email communication, computing and network equipment, cloud storage, data transmission, navigation using global positioning systems (GPS), most forms of transport, air traffic control, railway signalling, electricity distribution, passport and border control, health and police records, mobile and land-line communication, information technology and the internet and wearables. In every case, there may be one or more systems that are preferred by users usually because of innovative design, and features such as convenient sizing, ease of use, appealing looks, more comfortable ergonomics or cost.

Excellent engineering can command a significant premium operationally and aesthetically, and it is generally widely recognised by the user community; selection of a product is not always based simply on lowest cost. Reputation is a key factor here and companies will go to considerable lengths to protect and nurture their brand.

Excellent engineering stems first and foremost from creative thinking and inspiration that enables an idea to emerge when considering a problem. Aesthetics is often overlooked when putting together a specification for a product, especially when timescales are short and detailed thinking about implementation has to start almost immediately; the creative thinking step is often left out completely due to becoming completely focused far too soon on solving specific technical issues. There are skills in leading and nurturing group creative thinking that can lead to innovative and inspired solutions. However, they are often not explored in any depth or are seen as getting in the way of the more pressing needs to solve what are seen, usually by more result-focused individuals, as being the immediate and dominant issues to sort out.

Some might ask: "Does creativity lie in the domain of electronic engineering teaching?" If the desired result is excellent engineering then the answer has to be an unequivocal 'yes'. It is no coincidence that the words 'ingenuity' and 'engineering' have the same root, and ingenuity lies at the heart of all developments that become excellent engineering products. The job of engineers is to put technology into the service of humankind.

Supply of engineers

There is an acknowledged overall shortage of engineers in the workforce; and it is suggested that the UK needs to more than double the number of graduates with engineering degrees to meet UK demand[1]. The Institution of Engineering and Technology (IET) has been conducting an annual survey on Skills and Demand in UK Industry over the last decade, the purpose of which is to provide evidence as to whether the supply of qualified engineers is meeting demand in UK industry. Overall, the 2016 survey[2] suggests that there is a strong demand for new engineering staff in the UK, that experienced senior staff are difficult to find and that there is greater concern around the skills and experience of staff recruited to their first job (57% of surveyed employers are currently or have recently had problems recruiting senior engineers with 5-10 years' experience, and 53% find that there is a lack of available graduates)[3]. The latter is expressed in the responses to the question: *'Do you find that a typical recruit to an engineering, IT or technical role does not meet your reasonable expectations?'*, (62%, 53% and 45% of surveyed employers find graduates, school leavers/apprentices and postgraduates to be of concern respectively) for which the stated areas of concern are practical experience, business acumen, leadership and management skills, and overall, all recruits are perceived to have greater skills shortages than in past years.[4]

Degrees are seen as failing to provide appropriate practical skills or opportunities for students to gain company work experience (59% of surveyed employers believe that today's engineering degrees do not meet their needs because the degrees do not develop practical skills, 39% believe that degree courses are not up-to-date with industry, 29% find an absence of soft skills and 31% find that attracting candidates with sufficient work experience is a key issue).[5]

Overall though, the results of the survey suggest that job prospects for well-qualified graduate engineers are good as employers seek to fill positions. However, in the context of widening the talent pool, just 9% of engineering and technology staff are female and 63% of employers have no gender diversity initiatives in place[6]. In addition, only 6% of registered engineers and technicians (CEng, IEng, EngTech) are women.[7] One of the reasons quoted is the low female percentage, 15.8%, of engineering and technology undergraduates.[8]

Encouraging greater female participation in engineering provides a clear route to raising participation numbers while bringing on board an under-represented talent pool. The challenge here is far from being a new one; there have been campaigns and hundreds of initiatives in this area over decades and the female participation rate has barely changed. Whether this is because of or despite the campaigns and initiatives is essentially unknown, but however it is viewed though, the overall 15.8% female participation rate is undeniably low by any standards and anything that can be done to raise it would benefit the profession greatly.

Electronic Engineering at Royal Holloway

Royal Holloway, University of London, has taken the decision to open a brand new department of Electronic Engineering that will accept its first cohort in 2017. Part of the philosophy behind this move is to seek to attract more young women than the national average into the profession. This philosophy draws on the historical antecedence of the College, which was founded as a higher education college for women in 1886, and became co-educational in the 1960's. However, it requires more than just the desire to achieve such a change.

Electronic engineering has traditionally been seen as a science driven subject with entry qualifications of physics, mathematics and perhaps chemistry or another science. And yet, the IET Survey[2] indicates that today's industry is looking for talented graduate engineers who have practical skills, work experience, soft skills, business acumen, leadership and management skills. More importantly, recruits are perceived to have greater shortages in their skills compared to the past. This suggests that employers are looking for skills and experience over and above the underlying science and technology knowledge. This is not to suggest that the science and technology material is redundant. Rather, it suggests that consideration should be given to identifying core science and technology needs along with the practiced skills and experience in finding relevant knowledge and material as it is required. After all, technology that is current is continuously moving on. There are and there will continue to be new developments in component materials, component miniaturisation, advances in fabrication techniques, modifications to circuit design, and advances in knowledge through research and industrial needs.

Recruiting graduates with the necessary skills that enable them to enter employment ready to make contributions not only technically but also as members of teams is becoming increasingly difficult for employers to achieve in practice. For years the syllabi of many electronic engineering departments have been groaning with material that it is believed all graduates must be exposed to in order for them to contribute fully later in their professional lives. In practice, this is not the case; many will actually only focus on a subset of the material they were exposed to at university. They will meet new ideas and challenges based on novel research that they will have to explore for themselves; to achieve this, they need to be skilled in finding and processing relevant information.

In order to meet the needs of employers of reversing the perceived graduate shortfalls in practical skills, work experience, soft skills, business acumen, leadership and management skills, there has to be a reduction in curriculum content and a re-balancing between traditional lectures and practical activities. Couple with this the importance of releasing, enabling and developing students' creative skills to promote excellent engineering by allowing ingenuity to flourish in an open and supportive way without immediate critical put-down, a new model starts to emerge of an undergraduate experience that is appropriately fit-for-purpose.

The use of group activities with appropriately designed goals and purpose enables students to gain experience in and develop further their people management, leadership, team working, verbal and written communication skills, as well as their creative thinking and soft skills. Couple such activities with opportunities for work experience through a year in industry, vacation internships and/or timetabled activities that involve participation by visiting industrialists, and there is increased opportunity for gaining relevant work exposure and experience. For those who spend time in industry, both student and employer effectively gain a long interview; each will know whether a job is likely to work out if it were offered.

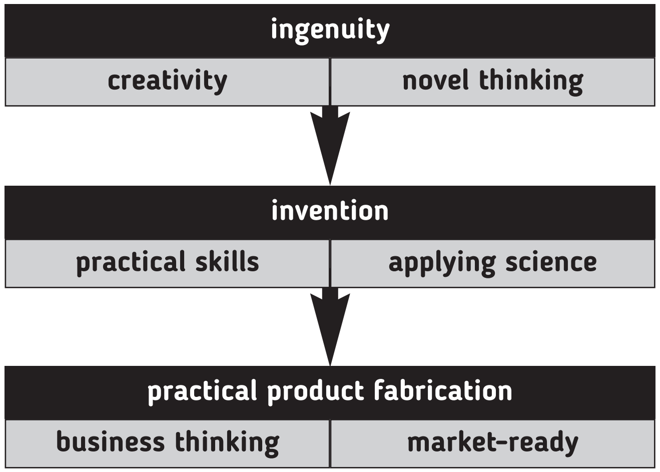

Fig. 1. The Royal Holloway three key stages for excellent engineering.

The over-arching process that will underpin electronic engineering teaching at Royal Holloway takes these ideas on board in the context of a three-stage process for excellent engineering in the context, for example, of bringing a product or App to market. These are: (1) ingenuity, (2) invention and (3) practical product fabrication and they are illustrated in figure 1. Ingenuity is the first stage which does not involve the application of science. Rather it requires the engagement of creativity and novel thinking, which in the context of engineering, would be a group activity. That creativity can be considered in terms of identifiable skills that can be both nurtured and measured[5]. The second stage involves invention through the design and demonstration of a working prototype that will make use of practical skills and apply scientific principles and technical knowledge and experience to achieve it. The third stage is one that turns an invention into a practical product that could go to market after manufacturing, financial and salability concerns have all been considered and appropriately addressed. These three stages are crucial to industrial practice where the realities of meeting targets and deadlines are greatly in focus. For a 'killer' product or App, a considered understanding from a variety of viewpoints is crucial as part of the decision making process as to whether to take to market or not.

In practice in the context of starting a new degree programme that will prepare graduates for the world of work, the nurturing of offering, working up and working with ideas that are not always one's own is a crucial step in building creative abilities in individuals. Group project-led activities with practical problems to solve where there is no right answer provide material and a structure within which students can gain experience working creatively. Such group project-led activities need to become a 'way of life' from day one. In order to foster a spirit of wanting to achieve an engineering result that might be termed 'excellent', opportunities will be offered for the presentation of group solutions of a given problem to an invited panel of experienced industrialists with prizes for the solutions considered overall to be the most creative.

The new Electronic Engineering degree programme at Royal Holloway is structured such that there are group project-led activities in all years except the third year, when students engage in their individual project. Guided working within the group projects will provide opportunities for experiencing and developing leadership and management skills. Other modules will provide

mathematics, computer programming and engineering material with incorporated more traditional laboratory sessions as appropriate. Practical creative problem solving will be based around high-level scenarios for which a solution is possible making use of the material from these other modules in group project-led activities. Experience will also be gained in core skills that are basic to excellent group working such as concise writing skills, clear presentation planning with persuasive vocal communication skills, creative thinking techniques, being a 'team' player, time management, leadership and management skills, soldering skills, searching and sorting relevant literature, referencing the work of others and respecting the views of others no matter what their background.

Conclusion

It is clear that the UK needs more engineers and that there is a pressing need to make an engineering career appeal to all sectors of the community. Industry has many requirements of their graduate employees but a key one is their ability to think and work in the context of the bigger picture around product innovations and the processes that achieve them. Creating ingenious solutions to problems for which prototypes can be produced and practical products can be made that can be sold at a realistic price is core to the engineering industry. This process is at the heart of excellent engineering and it is a process that is basic to professional thinking. In Royal Holloway's new degree programmes in Electronic Engineering, project-led group working will start from day one and continue through all years developing these skills in practice, except in the third when students will work on their individual project. The aim is to graduate women and men who are work-ready engineers whose focus is on creativity and ingenuity in problem solving, with an open mind for invention of prototypes that are seen through to salable products that will serve the needs of tomorrow's generations for years to come. In a nutshell, we will prepare tomorrow's electronic engineers for fulfilling careers creating technical solutions for an evolving world.

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Why the hard science of engineering is no longer enough to meet the 21st century challenges

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> *It's in Apple's DNA that technology alone is not enough — it's technology married with liberal arts, married with the humanities, that yields us the results that make our heart sing…*
>
> Steve Jobs (unveiling the iPad2), March 2011[1]

Executive summary

It has been more than fifty years since the engineering curriculum in the U.S. has changed significantly. In the 1950s, a strong emphasis on applied science and mathematics was introduced and since then it has become the heart of the engineering curriculum. However, much has changed in the last fifty years. The world has become much more complex and the Grand Challenges[2] we face now involve human behavior as much as they do technology. It is time to rebalance the engineering curriculum again, restoring some of the emphasis on professional skills[i]. This paper examines the reasons why now is the time to undertake such an ambitious project and what this will entail.

Historical background

The last major rebalancing of engineering education occurred after 1955 when the Grinter Report[3] marked a "sea change" in engineering education. This report established a sudden comprehensive shift in the undergraduate curriculum toward the hard sciences and mathematics. Calculus and physics became requirements for all engineering majors and faculty were expected to have a Ph.D. and participate in original research published in archival journals—just like their counterparts across campus in the natural sciences. In order to shift the balance in the curriculum, a shift in faculty credentials and interests was necessary, and the more ambiguous and less analytical aspects of the practice of engineering were no longer dominant. This major rebalancing was achieved over a few decades. Since then, the culture in academia (driven largely by the interests of the faculty) has continued to grow in the direction of applied sciences, with the underlying belief that the most important new developments in engineering will always flow directly from discoveries in the basic sciences. From an educational viewpoint, the foundational belief is that knowing more advanced science and math is inherently beneficial and increasing specialization is the key to making more important contributions as well as career success.

Without question, the rebalancing of the 1950s played an important role in propelling the nation to success in the Cold War and in building and sustaining the world's most powerful economy and standard of living. The role of engineering in creating the greatest technological achievements of the twentieth century is documented in a recent book[4] published by the National Academy of Engineering.

Emergence of complex Grand Challenges

However, the world has changed in many ways in the last half century, while our educational paradigm for engineering has not. For example, the technical challenges we face today are inherently more complex and global[4]. They transcend academic disciplines, political boundaries, and time zones. Challenges such as global security, sustainability, health, and enhancing the quality of life in an age of exploding world population will require more than new technologies or science. They will require more comprehensive and complete situational diagnoses, involving interdisciplinary understanding of the root causes and the consequences of any new technology introduced into the world. They will require global systems planning and analysis, involving social, economic, political, and even religious factors to obtain desired changes in human behavior on both local and global scales[ii].

Many of the challenges of today involve unintended consequences of the technologies developed in the last century. These consequences can often be traced to original conceptualizations that were too narrow or failed to include these "non-technical" dimensions to the problem in the first place. Those technologies often arose from analyses that ignored or underestimated the human behavioral aspects of the problem. To avoid this in the future will require multidisciplinary teams working together to diagnose problems and design solutions that result in fewer unintended consequences. The stakes are very high and are increasing with each generation, in part due to the increasing population, and in part due to the increasing power of (and relentless advances in) technology which, generally, enables a smaller and smaller number of people in each generation to affect the lives of a larger and larger number of others, both intentionally and unintentionally, and both for the better and for the worse.

The successful multidisciplinary teams needed to address these Grand Challenges must, of course, include members with advanced knowledge of the natural sciences and mathematics. The importance of continued advances in these fields has not and will not decline. It is implicit that we will continue to need experts and innovators in the pure and applied sciences and in mathematics, which has become the primary focus within our universities.

However, unless these advances are motivated by and integrated with equally sophisticated understanding of the complex human dimensions of the problems we face, they are unlikely to succeed. Furthermore, the need for synthesizers and integrators leading such teams is of fundamental importance. Like the conductor of the orchestra rather than a soloist, these multidisciplinary leaders are needed to shape the overall effort and produce an effective integrated result[5].

These special integrative skills are more closely related to the field of design than to analysis—which had been the hallmark of engineers before the Grinter report. Now that fewer engineers are prepared with these skills, the job of leading such teams in formulating and solving complex problems of this type often falls on others with much less preparation in the natural sciences—like politicians and business leaders. As a result, the critical need today for new insights that bridge technical disciplines and human behavior too rarely involves engineers. The academic field of engineering today does not adequately value broad thinking, synthesis, teamwork and consensus building, entrepreneurial mindset, and creative design as much as it does advanced analysis and new science. These "professional" skills were perhaps inadvertently de-emphasized in the curricular rebalancing a half-century ago.

Since much of the complexity of the Grand Challenges is the result of the inherent coupling between the technical and the human/social dimensions of the problems we face, the importance

of the humanities and social sciences in the engineering curriculum must increase. In this context, a recent report by the American Academy of Arts & Sciences[6] lays out a compelling case for the humanities and social sciences in any education today. They conclude that "the humanities and social sciences are the heart of the matter, the keeper of the republic—a source of national memory and civic vigor, cultural understanding and communication, individual fulfillment and the ideas we hold in common." It is these subjects that not only provide the essential insights for addressing the Grand Challenges, but also provide the nourishment for human understanding and wellbeing beyond the physical and financial. It is time to give our engineering students more opportunity to integrate them into their world.

> *"All of these problems at the end of the day are human problems," he said. "I think that that's one of the core insights that we try to apply to developing Facebook. What [people are] really interested in is what's going on with the people they care about. It's all about giving people the tools and controls that they need to be comfortable sharing the information that they want. If you do that, you create a very valuable service. It's as much psychology and sociology as it is technology."*
>
> Mark Zuckerberg (speaking at BYU)[7]

The rise in global competition

In about 1920, global human population reached one billion for the first time in history. Today, less than 100 years later, it is slightly above seven billion, and we are expecting about nine billion by mid-century. Every human society is likely to experience the effects of this sea change in population. It will create increased demand for clean water, food, energy, security, education, transportation, communication, and every other dimension to civilized existence. We have already seen major shifts in the geopolitical balance and more shifts are certain to follow.

In just the last few decades the BRIC (Brazil, India, Russia, and China) countries have experienced a rapidly rising middle class. One of the primary interests of the middle class is education for their children. As a result, each of these countries is currently involved in massive investment in increasing access to higher education. For example, in India alone, several thousand new engineering colleges have been created in the last decade, and China has been building entire new universities at a fast pace for the past decade. As a result, the world's largest airport is now in China. GE has now located the majority of its R&D personnel outside of the United States. China has now replaced the United States as the world's number one high-technology exporter. Eight of the ten global companies with the largest R&D budgets have established R&D facilities in China, India, or both. China has a $196 billion positive trade balance, while the United States balance is negative $379 billion. During a recent period in which two high rise buildings were under construction in Los Angeles, over 5,000 were built in Shanghai. The world is changing rapidly and the role of the U.S. is destined to become less dominant in all areas[8].

These emerging nations are looking forward with an attitude that they will do whatever it takes to build an innovation-driven economy. As a result, of the nearly 500 universities that have visited Olin College in the last five years for the purpose of gaining insight into how to produce engineering innovators, 70% of them are from abroad. These nations are very serious about making investments in education that will catapult them into a leadership role in the innovation economy. They implicitly assume that change and improvement are needed, and they are willing to make substantial investments to initiate it. In contrast, many American universities are relatively complacent. As a wise mentor once told me: "there is no more powerful force for conservatism than having something to conserve." America is still widely regarded as the world leader in higher education, so we have **a lot** to conserve. But if we remain flat footed while the rest of the world races ahead, they will eventually over-take us.

Decline in student interest in STEM subjects

Another major change of equal importance that has occurred in the last fifty years is the decline in student interest in STEM fields and the decline in quality and rigor of their preparation in K-12 in these fields. Fewer than 5% of the bachelors degrees awarded across America last year went to students who majored in any kind of engineering at any university in the nation[9] . Less than half of all incoming students who choose engineering as their major will graduate in engineering. And many of the students who drop out of engineering have higher grades than those who stay[iii] —so it is not a lack of skill or intelligence that drives students out of engineering. Students today are highly motivated to tackle the Grand Challenges of our age, but they don't see the narrow study of the fundamentals of natural science and math as the key to these problems[10]. They see the problems as more human than scientific. They are looking for a way to make a positive difference in the world—in the lives of people. They don't often see the study of engineering science and math as being directly related to the problems they see or care about.

This disconnect is frustrating, even heartbreaking. It too often leads to disillusionment and abandoning the field altogether. In the current generation of young college graduates, the problem of finding their "calling" seems separated from their college degree more than in previous generations. Too many students graduate from college only to return home to think about what they want to do with their life. To a degree that is much higher than previous generations, they postpone marriage and family, struggle with identity and purpose, and seem overwhelmed with the complexity and frustrations in life.

Emergence of extracurricular competitions that inspire students

A few bright spots that have emerged in the last few decades might offer some insight into how to improve the situation. In the last decade, more K-12 students have encountered robotics than ever in the past. The excitement of team competitions that parallel those in traditional athletics has been brought to an increasing number of schools, largely through the efforts of Dean Kamen and Professor Woodie Flowers (with support from John Abele and others in industry) through the FIRST organization[11]. The impact of student experiences in actually making and competing with complicated robotic systems while in high school is undeniable. It is clearly capable of transforming lives and leaving students with a sense of empowerment and intrinsic motivation to study STEM subjects.

Another example is provided by the large number of K-12 students today who discover the ability to create their own computer code or an "app" for their smart phone. The experience of creating something that works, something that is valued by peers, and something that can be shared broadly with others is similarly transformative for many students. It can also result in a sense of empowerment and intrinsic motivation in computer science and math. A recent example of this type of student engagement is provided by code.org and its "hour of code" program[12].

It is hard to avoid the observation that these two recent trends are inherently **experiential**, involve **making** things (rather than learning about things), and lie outside the traditional school curriculum. They require a complex number of non-technical skills including creativity and self-

expression, taking the initiative to learn independently (since these topics are not part of the traditional curriculum), collaboration with others, perseverance and determination to succeed (now sometimes referred to as "grit"), and communication – including advocacy – with others. The power of these experiential learning opportunities to address many of the major concerns in education is hard to overlook. It is also tragic that they had to be developed outside the school curriculum[iv]. The impact on students often extends beyond their knowledge and abilities, and includes a sense of empowerment, purpose, and direction in life.

Similar experiential learning opportunities are transformational during the college years, too. These include largely extra-curricular activities like the SAE Mini Baja race car competition[13], the ASME Human-Powered Vehicle competition[14], numerous computer "hackathons," entrepreneurial and business plan competitions, even some experiences in community service, music, athletics, and philanthropy, such a Toastmasters[15]. Students who find such opportunities and can successfully integrate them into their lives very often have better outcomes, educationally and in careers.

In addition, it is well known that students who complete a program with a required corporate internship have consistently better outcomes than those who do not. Corporate internships provide a well known example of what can happen if the engineering curriculum embraces the development of professional skills rather than ignores it. Students who graduate with an internship experience have a more realistic understanding of the context of engineering, and generally receive more and better career opportunities. Many companies give preference to candidates for employment that have internship experience and some companies restrict their recruiting efforts to students that have completed an internship within their company.

It is glaring that the missing professional skills in the preparation of engineers may be traced to the last rebalancing of engineering education, while many of the problems with student motivation and achievement in education today also appear to be related to the absence of these same contextual experiences that lead to enhanced professional skills.

The Internet and the shift from the "knowledge economy" to the "maker economy"

One final observation about the changes in the last fifty years may have a bearing on this issue. Before the Internet age, knowledge was much harder to come by. Just finding the facts was often a time-consuming chore involving books, libraries, and consultation with "experts." An important goal of education then was to produce experts who were recognized for their specialized knowledge of the facts. This expertise often translated into a professional career with financial success. Just knowing things was often intrinsically valuable and respected. (The popular TV game *Jeopardy!* epitomizes the implicit value our society has historically placed on "knowing things.")

But after the widespread establishment of the Internet (and powerful free search engines like Google), finding facts has become immensely easier and cheaper. The intrinsic value of knowing things has declined drastically—and permanently. To a large extent today, it matters much less what you know than it does *what you can do* with what you know.

Learning to make things is inherently experiential, as compared to learning about things, which is much more cerebral. Those who work in the arts have always understood this. The arts have long focused on self-expression, design and studio "thinking," and pedagogies that involve long hours of practice and emotional engagement—like recitals and concerts. Mastery, rather than knowledge, is the primary goal of the arts. In the arts, it matters as much or more *how* you say or do things than it does *what* you say or do. Technic is the hallmark of artisanship, not knowledge alone.

As a result of the Internet revolution, higher education is beginning to shift. MOOCs have emerged to provide widespread access to high quality educational content at very low cost. The old pedagogical paradigm of the expert professor as "sage on the stage" delivering content to rows and rows of quiet students who take notes and prepare to demonstrate knowledge on tests is beginning to shift. Now, we see the emergence of more experiential learning in the mainstream of higher education. The sage on the stage is increasingly being replaced by the professor in the role of coach, as "guide on the side," with students now arranged around tables in small groups working together during class on a "maker" project. The room is no longer quiet, and the students are more personally engaged in their learning, with public speaking and presentation a common expectation.

As a result, professional skills are becoming much more important in this new "maker university" format, taking center-stage as students must learn to collaborate and produce results together as they develop mastery. More and more, the focus of educational topics in this approach involves complexity, ambiguity, diagnosis, judgment, and human behavior, not simply mathematical answers or scientific facts. In the maker approach, the percentage of questions that have unique "correct" answers is declining. Judgment is increasing, and the skill of consensus building is becoming a prerequisite. In the university, as in industry today, students must learn to work productively with teams of others who have a different perspective or worldview. As a result, the ability to work effectively in teams and to assume a leadership role when needed has become much more common and important in the last fifty years, mirroring a shift in the organization of labor in the workplace during this period.

The time has come for another rebalancing of undergraduate engineering education

For the first time in more than fifty years, the time has come to significantly "rebalance" engineering education. No amount of doubling down on hard sciences and math will provide the professional skills that are needed now. The relative emphasis between hard sciences and professional skills in the degree requirements for engineering graduates must change to address the changing needs of our times. When corrected, there will be more required activities for students that involve "maker" projects, and fewer that involve learning just-in-case knowledge about topics that are never actually used. Teaching students how to learn independently, how to improvise in the face of the unexpected, and how to master the skills needed to make an impact will be more important than relentlessly trying to increase the scope and number of new scientific topics that cannot be covered in depth. The many extracurricular projects that today succeed in inspiring and empowering students—often in spite of, not because of our curriculum—need to be moved into the core curriculum. This can and is being done with success in some programs already. The result will be no less than a revolution in engineering education.

While our focus is on engineering education, it is important to recognize that a similar revolution is needed more generally throughout STEM education, and perhaps all of higher education.

> *Innovation is not simply a technical matter but rather one of understanding how people and societies work, what they need and want. America will not dominate the 21st century by making cheaper computer chips but instead by constantly reimagining how computers and other new technologies interact with human beings.*
>
> Fareed Zakaria[16]

What do we mean by professional skills?

In order to move forward with any large-scale movement like this, it is necessary to answer a number of important questions. These begin with a more detailed discussion of what we mean by professional (or soft) skills.

In recent years, many employers have complained about the need for more attention to professional skills in new engineering graduates. The list of concerns almost always focuses on non-technical abilities or "people skills" that represent attitudes, behaviors, skills, and motivations and not just knowledge. A precise and unambiguous description of these dimensions to the abilities of engineers is very hard to find, although many recurrent themes are apparent.

For example, the **ABET** accreditation criteria for all engineering programs (Criterion 3 Student Outcomes, (a)-(k))[17] contains 13 requirements for an accredited engineering degree. Six of these relate to professional skills rather than the use of the hard sciences. The professional skills they seek are described as follows:

(d) an ability to function on a multidisciplinary team

(f) an understanding of professional and ethical responsibility

(g) an ability to communicate effectively

(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and social context

(i) a recognition of the need for, and ability to engage in life-long learning

(j) a knowledge of contemporary issues

Many other employer and professional groups have provided descriptions of the professional skills that are needed for engineers today. Many of these groups have independently concluded that professional skills are of greater importance today than ever before, and that the educational process for engineers does not adequately address them.

For example, more than two decades ago, **IBM** began a call for the creation of the "T-shaped" engineer. Beginning with a study in 1990 of hybrid managers[18] then progressing to a call for T-shaped skills and finally to T-shaped professionals, IBM became convinced that a new hybrid field of "service science, management and engineering"[19] is needed in the 21st Century. This field depends on a workforce comprised of T-shaped individuals. The IBM concept of the T-shaped individual is illustrated in Figure 1 (overleaf).

The inclusion of human services within the engineering disciplines is gaining recognition within the engineering profession. In 2015, IBM chairman, president, and CEO Virginia Rometty was elected to the National Academy of Engineering for her leadership at IBM in establishing the field of services science.

Recently, **the Council on Competitiveness** with support from Lockheed Martin Company and others sponsored the National Engineering Forum[21]. According to their website, *"The National Engineering Forum (NEF) is a movement focused on creating solutions for challenges facing the U.S. engineering enterprise – capacity, capability, and competitiveness – the 3Cs. Momentum-building regional dialogues involve leaders from industry, academia, the media, non-profit organizations, and government in shaping the agenda and*

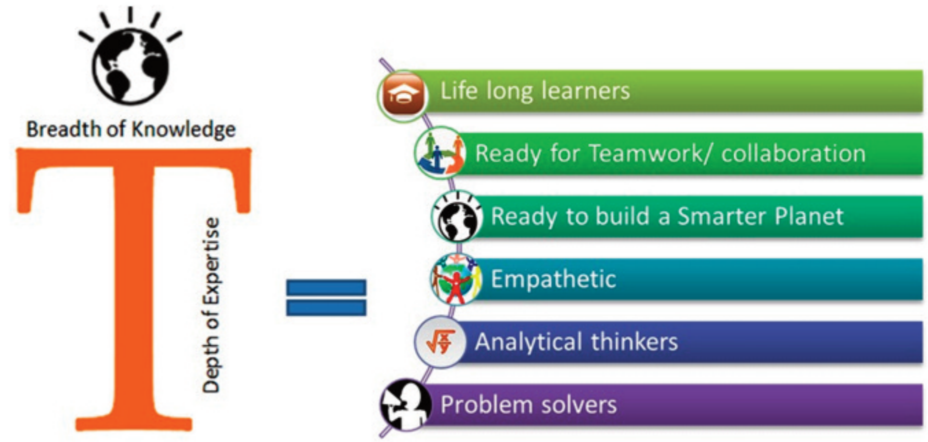

Figure 1: The IBM Concept of the T-Shaped Individual [20]. The vertical bar represents depth in a single technical discipline, and the horizontal bar represents the ability to apply knowledge across disciplines and to work with others.

building a community of action. The dialogues will culminate in a national cornerstone event in 2017." They explain that "capability" relates to the concerns about the need for **multi-disciplinary training** of engineers to meet the Grand Challenges, and "competitiveness" relates to concerns that **more creative and collaborative leadership** is required to build **partnerships with society through government and the media**. The NEF has sponsored about 20 regional meetings around the U.S. to discuss this agenda with a wide range of stakeholders and plans to convene a major national summit in 2017.

The **Business Higher Education Forum (BHEF)** is another broad-based group of industry and academic leaders dedicated to shaping the U.S. engineering workforce of the future. According to their website[22]: *"The Business-Higher Education Forum is the nation's oldest organization of senior business and higher education executives dedicated to advancing solutions to U.S. education and workforce challenges. Through the member-led National Higher Education and Workforce Initiative, BHEF is committed to developing new undergraduate pathways needed to keep regions, states, and the nation economically competitive. BHEF and its members drive change locally, influence public policy at the national and state levels, and inspire other leaders to act. BHEF works with its members to develop undergraduate programs in emerging fields that can be applied to a variety of professions to correct workforce misalignment."* The BHEF is active in developing definitions of "**workplace competencies**" and "academic content knowledge" that align better with emerging national needs and launching partnerships between industry and academia aimed at creating innovative new programs to shape the future workforce in engineering.

The **STEMconnector** is another organization involving a broad community of more than 3,700 national, state, local, and federal STEM organizations. As described on their website: *"STEMconnector® is a consortium of companies, nonprofit associations and professional societies, STEM-related research and policy organizations, government entities, universities and academic institutions concerned with STEM education and the future of human capital in the United States…"* Of particular interest is a recent STEM Innovation Task Force (SITF) that has been working for many months on the demand-side requirements of STEM professionals. Their report, STEM 2.0[23], provides an outline of their view

of the professional skills needed for the STEM workforce of the future. The graphic in Figure 2 highlights their relevant findings.

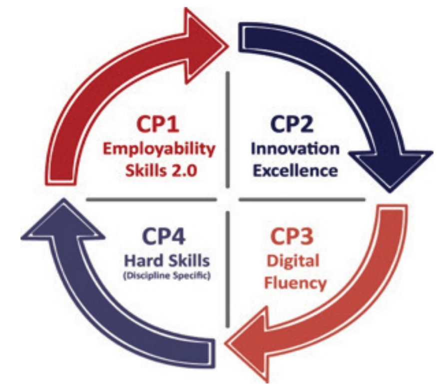

Figure 2: STEMconnector Innovation Task Force report (STEM 2.0) on the competency platforms (CP) needed in the workplace today.

As described in the report, "STEM 1.0 focused, rightly, on STEM content, whereas the next stage for our students and future workforce is to master **context**." The graph in Fig. 2 illustrates the four "competency platforms" (CP) identified by the SITF as necessary to achieve STEM 2.0. In particular, CP1 and CP2 require a quantum improvement in professional skills.

Employability Skills 2.0 (CP1) are identified as "the **behaviors above and beyond technical skills** that enable STEM employees to create stakeholder momentum to commercialize ideas, or in short career skills. It is the ability to **present and 'sell' their ideas to others; to function in teams; to develop business acumen; to develop leadership skills; to navigate across a complex matrix of global organizations.**"

Innovation Excellence (CP2) requires developing the "process of transforming ideas into new and improved systems, services or products that enhance the value of existing resources or create new ones. Innovators **identify opportunities** and use them to **drive change**. Innovation excellence requires a **'holistic' multi/trans disciplinary skill set**."

In addition to these recent industry studies and reports, the **National Academy of Engineering** has also endorsed similar increased emphasis on professional skills. For example, the **NAE Grand Challenge Scholars Program**[24] was launched in 2009 to recognize and reward those engineering students who graduate with additional preparation in five areas beyond technical competence, including (1) a **hands-on project** or research experience related to a Grand Challenge; (2) an **interdisciplinary curriculum** that involves **public policy, business, law, ethics, human behavior, risk, and the arts, as well as medicine** and the sciences; (3) **entrepreneurship experience** that prepares students to develop market ventures that scale to global solutions in the public interest; (4) a **global dimension that instills awareness of global marketing, economic, ethical, cross-cultural, and/or environmental concerns**; and (5) **service learning that deepens students social consciousness and their motivation to bring their technical expertise to bear on societal problems**.

On March 24, 2015, more than 120 deans of engineering from across the nation presented letters of commitment to President Obama to establish a Grand Challenge Scholars Program on their campuses and graduate more than 20,000 engineers in the next decade with these enhanced professional skills[25].

These industry and academy reports are also supported by research results. For example, a recent thesis at MIT[26] involving a survey of nearly 700 mechanical engineering graduates about 10 years after commencement reported that students learned an extensive list of engineering science and mathematics subjects at MIT, but that they found much less use for this material in their career than they did for professional skills—which they mostly had to learn on their own after graduation. They reported that their current position required relatively little direct competence in the engineering sciences, but instead required substantial proficiency and even leadership in professional skills in order to advance. They reported that they used the professional skills daily but engineering and science much less frequently.

More recently, the NAE published a report titled **Educate to Innovate**[27] that, among other things, identifies the factors that influence innovation. As presented in the report, "the United States must significantly **enhance its innovation capacities** and abilities among both individuals and organizations. Innovation capacity should be a new indicator of US workforce readiness to compete successfully in the global economy… **A new educational paradigm is needed** to help current and future American workers remain competitive… Academic environments, from the earliest ages through continuing education, can be improved—and even designed—to enhance this ability…The skills and attributes identified in the study include: (1) **creativity**; (2) **dissatisfaction with the status quo**; (3) **intense curiosity**; (4) the **ability to identify serendipitous moments**; (5) **willingness to take risks and to fail**; (6) **passion**; (7) knowledge of their field; (8) the **ability to identify good problems/ideas**; (9) the ability to **work at the interface of disciplines**; and (10) the ability to **sell an idea**."

Although not directly aimed at engineering graduates, it is noteworthy that the **World Economic Forum** also recently published a report[28] that presents a new summary of the skills needed for the 21st Century of all graduates. From the executive summary: "To thrive in a rapidly evolving, technology-mediated world, students must not only possess strong skills in areas such as **language arts**, mathematics and science, but they must also be adept at skills such as **critical thinking, problem-solving, persistence, collaboration, and curiosity**.

Now, collecting ideas from all of these sources, a partial list of the professional (or soft) skills that are needed might include the following:

A Summary of Professional Skills

- Ethical behavior and trustworthiness
- Employability skills, including self-confidence and positive outlook, accepting responsibility, perseverance, sincerity, respect for others, good judgment, etc.
- Effective communication, including advocacy and persuasion
- Effective collaboration including leadership, followership, and consensus building
- Resourcefulness and the capacity for independent learning
- Entrepreneurial mindset and associated business acumen
- Inter- and multi-disciplinary thinking
- Creativity, curiosity, and design

- Empathy, social responsibility
- Global awareness and perspective

(It's important to note that the skills identified here may not be completely independent. To my knowledge, there are no substantial research studies that undertake to identify the level of interdependence among these skills.)

Do these professional skills make a significant difference?

The proliferation of independent industry reports calling for an improvement in professional skills while remaining nearly silent on the need to keep up with emerging developments in the hard sciences and technology demonstrates widespread agreement that more improvement is needed in soft skills than anywhere else. Except for a few special cases (such as cyber-security) it is difficult to find industrial reports that call for additional or new technical subjects in the engineering curriculum.

However, this raises the question of whether individuals that make the investment to develop these skills experience a difference in their personal career trajectory. One of the ways to approach this question is to review the advancement and financial opportunities available to those individuals in comparison to those with lesser professional skills. Naturally, competent engineers with well-developed professional skills stand out when leaders look for individuals to promote into leadership positions. In fact, in most cases, professional skills are far more important for senior leadership appointments than high levels of technical competence. Substantial financial reward usually follows advancement into leadership positions. Recent reviews of salaries of engineers[29] confirms that those who ascend into leadership (management) positions experience a significant increase in salary and benefits.

In addition, college placement officers also confirm[30] that for graduating seniors with similar technical preparation, those with well-developed professional skills consistently receive more employment offers and higher starting salaries than those without these skills. Interestingly, about 14% of the new employees selected at Google last year[31] had no college degree at all, in spite of the fact that Google receives tens of thousands of qualified applications. Lazlo Bock, Senior Vice President for People Operations at Google, explained that they sometimes look for qualities that do not line up with college transcripts. So, certain forms of professional skills are weighted more highly than a university degree at Google.

Finally, studies of companies that excel in the market place often reveal that the corporate culture plays a substantial role in their success[32]. Those companies with a culture marked by higher levels of professional skills tend to out-perform those that do not over the long term[33]. It is hard to identify a downside to building a company on a foundation of widespread professional skills.

> *I want to talk with everyone about innovation. We often say that America and Europe are more innovative than us, that China's innovation is not good and that the education [jiaoyu] system is to blame. Actually, I think China's jiao is fine. The problem is with the yu. In terms of jiao, China's students test better than anyone in the world, but yu is about fostering culture and emotional IQ… [Innovations] will only come regularly if we rethink our culture, our yu, our having fun… our entrepreneurs need to learn how to have fun, too...*
>
> Jack Ma (founder of Alibaba)[34]

But can professional skills be taught?

Reviewing the list of professional skills, it is clear that these abilities extend beyond traditional course content knowledge and focus instead on a set of attitudes, behaviors, and motivations. Collectively, we might refer to these as a "mindset." But can education produce these attitudes or mindset? Is it possible to write a textbook, provide a set of lectures, and create a set of exams that will guide students to reliably develop the skills we seek? This is a difficult question that extends well beyond the boundaries of traditional engineering courses.

The fact is that attitudes and behaviors are only minimally affected by knowledge alone. They almost always require personal experiences that challenge beliefs and require extensive practice to build habits of mind. These psychological factors are largely unfamiliar to engineering faculty (and to many others, as well!). However, it is important to realize that business schools have long specialized in providing instruction aimed at improving teamwork and leadership skills, sales and marketing, entrepreneurship, etc. There are well established educational programs in these areas, although they may focus more on skills and knowledge than attitudes.

Consider the first professional skill in the list above: ethical behavior. Nearly every time a national scandal occurs in the financial world (like Enron, Bernie Madoff, or the recent Global Recession) business schools increase their emphasis on courses in business ethics. However, these courses are usually based on intellectual content derived from the philosophy of ethics with a focus on very complex decisions in cases involving trade-offs between two or more imperfect options. As fascinating and valuable as such courses may be to public policy debates, there is very little evidence that they are effective in reducing the likelihood that business graduates will avoid ethical violations themselves.[35 36]

However, a different approach that focuses on personal behaviors involved in confronting ethical violations in the workplace, together with practice in role-playing to build confidence and personal skills, has shown promise in changing mindset and behavior.[37] As in other examples of professional skills, the problem often lies not in a failure to understand at an intellectual level, but rather in a failure to develop the conviction and the skill to take personal action to address obvious problems when they occur—in spite of the personal inconvenience involved.

One of the most common goals of a liberal education is to produce "critical thinking" among graduates. Nearly all colleges and universities claim this as an important objective. But what, exactly, is critical thinking? One example might be provided by Dr. James Ashton[38] who, in the 1980s while serving in a leadership role at General Dynamics Corporation in producing the Trident Submarine, became concerned in comparing his personal observations with corporate reports on financing of the project. In an attempt to make sense of the situation, he drew the independent—and most inconvenient—conclusion that something was fundamentally wrong. This led him to confront top management with his independent analysis and ultimately to leave the company, eventually participating in a 60 Minutes interview with Geraldo Rivera and testifying before Congress. This sense-making, independent conclusion and personal action are all important ingredients in what we hope "critical thinking" really means.

However, it is interesting to compare this example with the most common method for producing critical thinking in higher education. In essence, critical thinking is assumed to result from the collective experience of taking a series of lecture courses for four years from highly educated faculty members who are experts in their research disciplines (but rarely in corporate practice). The courses are selected from several lists of approved electives, three from list A, two

from list B, etc. However, some people have begun to question whether this whole approach is effective in producing the critical thinking we seek. After all, the students are exposed only to faculty members, not to practicing professionals. The environment they experience is that of academia that is marked with academic freedom, and not that of the competitive marketplace. There is rarely an independent assessment process intended to monitor the cumulative development of critical thinking.

For example, some years ago, President Liz Coleman of Bennington College in Vermont concluded that this process is fundamentally inept in producing critical thinkers (and other things), and she led a process of gut-wrenching change in her institution to literally reinvent a liberal arts college. She is now an outspoken advocate for such profound change throughout higher education.[39]

Another of the professional skills on the list is that of an entrepreneurial mindset and associated business acumen. Over the last two decades, engineering schools have begun to accept that students should learn the basic principles of entrepreneurship. Twenty years ago, it was rare to find an engineering school that was willing to make room in the curriculum for this subject, whereas today it is difficult to find an engineering school that does not already have such a program or is in the process of creating one.[40]

To meet the growing demand for teaching entrepreneurship in engineering, several well organized independent programs have been developed. One of the most successful is the Kern Entrepreneurial Engineering Network (KEEN).[41] This network of 19 engineering schools around the U.S. is focused on graduating engineers with an entrepreneurial mindset, not just technical skills. The KEEN network has a well-developed educational approach involving four cornerstones: business acumen, customer engagement, technical fundamentals, and societal values. But developing an "entrepreneurial mindset" is their highest goal. (Other well organized educational programs focused on engineering entrepreneurship also exist, including the EPICENTER program at Stanford University.[42])

There are many possible definitions of an entrepreneurial mindset. However, at the foundation it may rest on a powerful "can-do" spirit, a focus on opportunities rather than challenges, and the "abundance" mindset (which I will return to later). Of course, it takes much more than a mindset, but it may be hardest to define and cultivate the mindset.

I recently read an article in the *Wall Street Journal* that included an interview with President Peretz Lavie, President of The Technion in Israel.[43] The Technion is regarded as a significant factor in Israel's becoming known in many circles as the "start-up nation." The persistent existential threats faced by Israel would seem to fly in the face of this reputation as the engine of entrepreneurship for the entire region. However, in the article, President Lavie explains: " 'We have to be on our tiptoes and have to think ahead,' he said. To live here, he adds, one has to be optimistic—an essential attribute for entrepreneurs".[48] Clearly, he believes that the unusually challenging environment in Israel may have strangely contributed to the development of an entrepreneurial mindset there.

Unpacking this for a moment, I believe what Professor Lavie is saying is that entrepreneurs are people who *must* be optimistic. They must naturally have a mindset that predisposes them to imagine a better future is always possible, and that future depends on our taking initiative and creating the change that will make it so. This is in contrast to an opposite (cynical) mindset that believes future improvement is hopeless, imagines we are victims of some larger system or circumstance, and focuses efforts on finding someone else to blame.

This explanation of an entrepreneurial mindset is clearly related to the contrast between a "scarcity" vs. "abundance" mindset. These concepts were explained by Stephen Covey:

> *Most people are deeply scripted in what I call the Scarcity Mentality. They see life as having only so much, as though there were only one pie out there. And if someone were to get a big piece of the pie, it would mean less for everybody else.*
>
> *The Scarcity Mentality is the zero-sum paradigm of life. People with a Scarcity Mentality have a very difficult time sharing recognition and credit, power or profit – even with those who help in the production. The also have a very hard time being genuinely happy for the success of other people. …It's difficult for people with a scarcity mentality to be members of a complimentary team.*
>
> *The Abundance Mentality, on the other hand, flows out of a deep inner sense of personal worth and security. It is the paradigm that there is plenty out there and enough to spare for everybody. It results in sharing of prestige, of recognition, of profits, of decision making. It opens possibilities, options, alternatives, and creativity. …It recognizes the unlimited possibilities for positive interactive growth and development, creating new Third Alternatives. …It means success in effective interaction that brings mutually beneficial results to everyone involved.*[44]

It is much easier to teach "business acumen" and techniques like accounting or business plan development than it is to promote an entrepreneurial mindset. Obviously, this involves personal attitudes and behaviors, and derives from a special learning culture.

So, is it really possible in education to shape a student's mindset or mental outlook? I believe it is, at least to some extent. In fact, I believe it may be happening every time we interact with students—whether we are aware of it or not.

For example, last fall I heard in the popular press[45 46] about an experiment with young children related to the Thanksgiving holiday. Apparently, the teachers had noticed that their students had a very weak sense of the meaning of the holiday. The students did not associate Thanksgiving with a sense of gratitude. So, they applied a curriculum to develop a sense of gratefulness. This consisted of asking students in one classroom to keep a journal in which each day they wrote down a few things that happened for which they were grateful. At the end of the week, the teacher conducted a brief class discussion of journal entries, and after several weeks they conducted an open class discussion in which the students were asked to envision the future as they expect it to be. Not surprisingly, the students envisioned a future with many positive possibilities, and were looking forward to an opportunity to engage in making a positive difference in the world. However, in another classroom down the hall, they applied a curriculum that instead of requiring students to identify several things they were grateful for, they identified several things that they regarded as hassles. In other respects, the process was identical. It might not surprise you that at the end, they found that the hassles curriculum produced a student outlook on the future that was much less positive. Students in this case saw a future with negative events, frustration, and little to be grateful for. It did not result in a mindset of abundance. These results are consistent with published research in experiments with college students in the field of positive psychology.[47]

> *Reflect on your present blessings, of which every man has many, not on your past misfortunes, of which all men have some.*
>
> Charles Dickens, (M. Dickens, 1897, p45)

Who should take responsibility for teaching professional skills?

Since engineering faculty members were hired for their expertise in the technical disciplines, rather than in professional skills, few of them are likely to be well-prepared to take responsibility for teaching the professional skills. Furthermore, in previous generations many people just assumed that the responsibility for preparing the attitudes and behaviors of students was that of the parents, not teachers. Other people have noted that students who have a co-op experience in industry (or similar substantial personal experience working in a professional environment) seem to develop professional skills at a noticeably higher rate than students who have no such experience. Furthermore, teaching professional skills appears to be much more complex and nuanced than teaching knowledge of even skills that may be easily defined and measured. As a result, there are many good excuses to not take responsibility for teaching these skills. Undoubtedly, this fact plays an important role in creating the unfortunate situation we find today where they are largely overlooked.

Perhaps engineering schools should begin by sending their students to a business school to take the programs already developed there. It is hard to ignore the well-developed educational programs in this area that are available in most business schools today. However, this avenue is rarely taken by engineering schools. Why is that? Is it because of the logistics or financial consequences involved? Is it because of cultural factors between the faculty in each school, or the cultural factors between students?

While it is perhaps the most costly alternative in terms of time and resources for an engineering school, I think a good case can be made that the best alternative may be for engineering schools to take responsibility for teaching these skills within their own programs. For example, when attempting to teach another of the professional skills—effective communication and writing—it is much more effective if these skills are embedded in every course in the school (i.e., "writing across the curriculum") than it is when sending the students to the English Department to take a course or two there. If we understand how important professional skills are, and we want our students to respect them, then we should embrace them in everything we do. Adding at least a few faculty members within the engineering school who can take the lead in developing not just a curriculum, but a culture that builds professional skills, is perhaps the best approach. Then building a learning model that not only teaches about engineering, but teaches students to be engineers is how this can be integrated into the entire curriculum. This learning model should include a substantial engagement with industry, where the culture is authentic and is driven by market forces, rather than concerns about ideas alone and publishable research.

In summary, the time has come to embrace the professional skills and fold them into the mainstream in the engineering curriculum. No longer can we afford to pass the responsibility to someone else. We are the last stop on the educational train for our students—if they don't get these skills from us, where will they get them?

Discussion questions

- How important do you feel professional skills are for engineers today? Which two or three skills do feel are most important for career success and for society?
- Whose responsibility do you think it is to teach professional skills in engineering?

Footnotes

i Professional skills are sometimes referred to within engineering schools as "soft skills." They generally do not depend on an understanding of science or math. However, they have proven much more difficult to define and teach than the more traditional subjects. In that sense, the term "soft skills" may be a misnomer.

ii National Academy of Engineering, *The Engineer of 2020: Visions of Engineering in the New Century*, 2004, National Academies Press, Washington, DC.

iii This is especially true of those who are women.

iv The widespread emphasis on standardized testing creates little incentive or opportunity for educational experimentation, although some non-traditional schools (such as High Tech High School in San Diego—and a growing number of others) are successfully pioneering a very experiential learning environment that provides nearly everything described in this paragraph.

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Internationalising the curriculum – a transnational partnership in renewable energy

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Introduction

The supply of clean energy, across all economies and geographical zones, is one of the world's great engineering challenges. Energy supply is multi-disciplinary and multi-national. It demands creative and varied responses, to meet the needs of different communities and settings. The study of energy supply is a major aspect of many engineering degree programmes. Such study demonstrates a satisfying dependence on fundamental scientific concepts, and inter-disciplinary engineering activity. Staff from the University of Derby (UK) and Nango Solar Limited (Kenya) have recently begun working together in an informal partnership on a number of projects to the mutual benefit of the two organisations. The collaboration acts as a catalyst for widening and internationalising the Derby curriculum, implemented initially in a final year undergraduate module *Renewable and Smart Energy Systems*.

The Partnership

Nango Solar is based in Kisumu, Kenya, on the shores of Lake Victoria. The company designs, develops and produces a range of solar-powered products, for example egg incubators, charging stations for domestic lanterns, security lighting, and water pumping for small-scale irrigation. On a larger scale they design and install systems for solar power supply to hospitals, clinics and education establishments.

The University of Derby, in the centre of the UK, has an ongoing teaching and research interest in renewable energy. Modules on the topic appear in the curriculum from undergraduate Year 1, and are supported by well-equipped laboratory facilities. Staff have teaching and research interests which include energy acquisition, power electronics, intelligent control, and Matlab/Simulink modelling.

Each organisation has needs which can in part be satisfied by the other. The university wishes to engage proactively in applied research and to provide teaching informed by recent research and relevant professional experience, thereby providing a curriculum fit for students of all nationalities. Nango Solar wishes to develop its technical expertise and can benefit from Derby's research and design expertise. To Derby, Nango Solar offers exposure to unfolding case studies through live data and visiting lectures, as well as project topics at undergraduate and postgraduate level, opportunities for joint applied research, and career and entrepreneurship ideas and role models for graduates.

Internationalising the Curriculum

Motivation for internationalising the curriculum (IC) arises in a simple sense from a wish to make studies relevant and useful for the international student. The University of Derby is not alone in drawing its students from many countries, particularly in its engineering programmes, so has a clear ambition for IC. The home student can also benefit from this internationalisation. An early definition of IC is "the process of integrating an international dimension into the research, teaching and services function of higher education."[1] A simple implementation of this could be by the addition of case studies drawn from different parts of the world. However the idea has been extended to a much broader ambition, that an internationalised curriculum exists to develop "global citizens". This is usefully defined by Clifford and Montgomery[2], or Clifford[3], as adopting "a framework of global perspectives, intercultural awareness, and responsible citizenship".

Study in energy supply is a natural vehicle for IC; it impacts all countries, and inevitably has transnational aspects to it. Partnerships such as the one described here provide a useful catalyst.

Example Cooperative Project

Nango Solar's customers are located predominantly in rural areas, where the mains electricity supply is either absent or unreliable. In such settings, the potential for application of solar energy is particularly great, as reported by Ford[4], with patchy implementation already in place. The challenges of systematic implementation are outlined by Ahlborg and Hammar.[5]

Nango Solar has over several years been providing energy expertise to Haydom Lutheran Hospital[6] in Tanzania, starting with a detailed study and report to management in 2013. Hospitals have very distinct energy needs, involving both high (and hence costly) demands and a requirement for high reliability. Other essential services, such as water supply, may in turn depend on the energy supply.

Arising from the earlier review, Haydom Lutheran Hospital (with partial sponsorship from Friends of Haydom in Norway) has recently installed a pilot 5 kW solar system. The design criteria for this installation were presented to a group of Derby final year students in a visiting lecture from Nango Solar during 2016; students were able to see and question a project being specified and implemented. As part of their coursework they went on to propose solutions to the design need.

In the actual installation, Nango Solar applied a Sunny Boy inverter.[7] They further applied the manufacturer's design software[8] to select the particular inverter, specify the photovoltaic arrays, and model system performance. The system, comprising two arrays and one inverter, was installed in late 2016 and came into service shortly after. Output is monitored through the internet by the system operators and maintainers in East Africa, by the sponsors in Norway, and by Derby staff and students in UK. As an example, Figure 1 shows output over a day in January 2017, with the afternoon energy supply apparently interrupted by brief periods of cloud.

Derby University partners have meanwhile modelled the same system in Matlab, and are comparing the predicted performance with actual data. The findings will inform a progressive rollout of solar electricity generation at the hospital. We hope further to report the findings of this study in a conference or journal paper later in 2017.

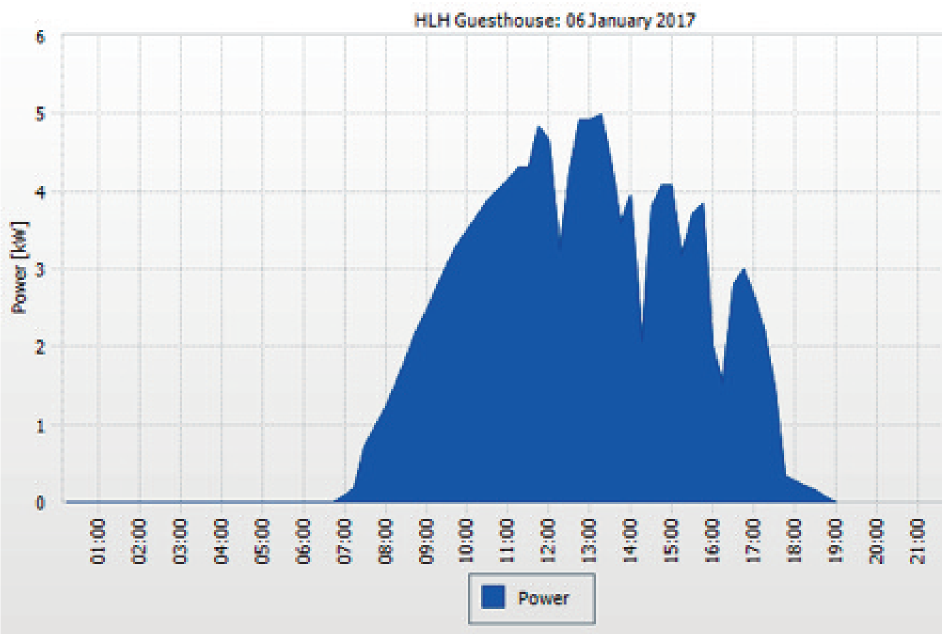

Figure 1

Evaluation and Conclusion

This is a new relationship, in its early stages, yet a number of clear positives have already emerged. The Renewable and Smart Energy Systems module has run in one iteration with this partnership active. Aside from the East Africa links outlined, case studies from Switzerland, the USA, several Scottish islands, England, and other parts of Africa were also used in the module delivery. Students from Gulf countries may well feel that their region is not yet well-represented. Some progress has been made towards the "global citizen" ideal, and certainly this partnership gives clear evidence of engineers influencing society for the better. Although the standard student evaluation was undertaken upon module completion, the staff did not take the opportunity to explore the students' perception of the internationalised curriculum, an omission we aim to correct on the next iteration.

Derby University has been able to advance its research agenda, to energise its teaching in renewable energy, to progress towards an internationalised curriculum, and to offer teaching informed by research. Nango Solar has been able to consult Derby staff on design issues and to review new ideas and concepts with them. We look forward to further benefits emerging.

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Case study: coordinated design and employability teaching

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Abstract

The University of Nottingham appointed a professional engineer with twenty-five years of design experience to enhance industrial realism in teaching. The aim was to improve employability and student satisfaction against a low baseline for these measures of success. After determining that the problem centred on design teaching, a multi-year programme of practitioner-led design teaching was devised and delivered which led to large increases in employer reputation, graduate employability, NSS scores, and consequent improvements in rankings such as the THES.

I was appointed Associate Professor of Chemical & Environmental Engineering at the University of Nottingham in 2011, where I developed two inter-related strands of teaching, namely employability and engineering design. My area of interest lay in identifying the gap between academic and professional engineering, which forms the basis for initiatives such as CDIO and the work of James Trevelyan. I was interested in closing this gap using intensive exposure to real engineering design problems, engineering practitioners, and process plants.

My teaching practice is ultimately based squarely on reflection on my own professional engineering practice, (kept current by continuing to practice, and through frequent interactions with my fellow practitioners). When I entered HE I thought of myself as essentially an applied scientist and mathematician, but I realise now that very little of my twenty-five years as an engineer have been spent doing science or mathematics. My design teaching practice is based more in reflection on my own design practice and what Cross (2001)[1] calls a *"designerly way of knowing"* than it is on science or mathematics.

To quote Figueiredo (2008)[2]:

> *The design dimension sees engineering as the art of design. It values systems thinking much more than the analytical thinking that characterizes traditional science. Its practice is founded on holistic, contextual, and integrated visions of the world, rather than on partial visions. Typical values of this dimension include exploring alternatives and compromising. In this dimension, which resorts frequently to non-scientific forms of thinking, the key decisions are often based on incomplete knowledge and intuition, as well as on personal and collective experiences.*

Engineers are great communicators, but the things we communicate have simultaneous interactions in multiple dimensions, and we must communicate them accurately and unambiguously. The most elegant words or calculations are still essentially a linear string of arguments, and we need to communicate a multi-dimensional interrelated whole. We consequently spend a lot of time with drawings, as discussed by Ferguson (1994) in *Engineering and the Mind's Eye*.[3]

Inaccurate communication between engineers can have high costs. Frequently, lives can be at stake. Professional engineers consequently use several standardised specialised drawing formats for the purposes of communication, but most chemical engineering departments worldwide teach very little in this area.

To cite those most relevant, I am convinced by the arguments made by Ferguson[3] that there has been a privileging of the mathematical over the visual and verbal in HE which has led to a separation of highly mathematical academic approaches from largely drawing and discourse-based professional practice. Both Vincenti's (1990) account of '*What Engineers Know and How They Know it*'[4], and Koen's (2003) '*Discussion of the Method*'[5] have crystallised my ideas on the distinctive epistemology of engineering. More specifically, in the case of design teaching, Meadows' '*Thinking in Systems*' (2009)[6], Petroski's '*To Engineer is Human*' (1992)[7] and Pugh's (1990) '*Total Design*'[8]; as well as the CDIO (Conceive, Design, Implement, Operate) movement's output[9] and Trevelyan's (2015) '*The Making of an Expert Engineer*'[10] have helped to flesh out my ideas of how design teaching needs to change to align with what engineering designers actually do.

It might seem that, as an educationalist, I should be discussing "my interpretation of … the distinctive epistemology of engineering", and "my opinion of" what engineering designers do, but I am an engineer as well as an educator. I know what engineering designers do after twenty-five years of being one, and teaching others how to be one. I know that engineers communicate mainly with drawings, and why they do so. My ideas do not come from the books I mention: these are simply works whose authors understand engineering as I do.

It seems to me that the absence of drawings from chemical engineering degrees is related to Ferguson's[3] claims about the devaluation of graphical reasoning. If we believe in the existence of either learning styles, or of multiple intelligences, we might think it highly inappropriate that we are predominantly teaching and testing students' mathematical ability, rather than the highly professionally important "spatial intelligence".

Design teaching in chemical engineering has become highly theoretical and mathematical, and rather unlike any aspect of either engineering or design as practiced by professional engineers. This is an amplification of the problems noted by the CDIO movement. There is some discussion of this in pedagogic literature – see for example Clark and Andrews (2012)[11], but since there were in the region of just 54 engineering practitioners in all UK chemical engineering University departments at last count (Prichard (2017))[12], professional voices have been drowned out.

I knew from my own experience in professional practice and many conversations with my fellow practitioners that a lack of preparation of graduates in this area was commonplace, but I wanted to have as solid a ground as possible for what I knew would be a controversial issue. I created a LinkedIn group for Nottingham Chem. Eng. alumni, (which had almost 600 members) and (as well as gathering employment data) asked them a simple question: "how well did we prepare you to work as an engineer?"

The answers were consistent: most significantly (and especially in recent years judging by graduation year), students had not been taught to produce or even read key engineering drawings, or use professional design software. This is not just a question of drafting skills – as Trevelyan[10] discusses, these drawings are tools for thought, ways of breaking a design problem down into different perspectives for analysis, and the key means of communication and collaboration between engineers.

The key challenge for a teacher/practitioner attempting to teach a professional process design methodology in a HE environment is to understand both what they know about the subject and

how they know it, as it is very unlikely that they were taught it formally. Trevelyan discusses this issue in detail in "The Making of the Expert Engineer".[10] Engineering design is a creative activity, which is supported by engineering science and applied mathematics. These disciplines do not help us with the crucial imaginative part of the design process; they only help us rank and select from the alternative solutions we have imagined.

If I am to make engineers, I must grow in my students the courage to make intuitive leaps, to have a feel for relative approximate size, cost, and practicality and so on. I therefore model for my students a professional engineer, and I bring other practitioners into the heart of the course, delivering course content, setting assessments, offering feedback direct to students on their work.

It might seem from the language here that I am describing a teacher-centric approach, but that is not the case. I offer students a model of how an engineer is, and I do tell them how engineering is done. Most of the students' time will however be spent teaching themselves to design the plants they have been asked to design in groups. There is far more peer-learning and self-teaching than didactic learning. I am however keen to avoid the doctrinaire application of XBL, whose failings Kirschner (2006)[13] discusses. I therefore give detailed and explicit instruction at first. I require students to design plants, rather than to invent how to design them for themselves, and feedback from first year students suggests that they perform better with a certain amount of direct instruction. The scaffolding of instruction is reduced towards zero as student mastery increases.

I brought the two strands of my teaching interests together in the "design strand" which I developed at the University of Nottingham. This design strand formed a vertically- and horizontally-integrated contextualising strand running through the chemical and environmental engineering degree courses from the very first week.

I am aware of the academic debate around the gap between academia and professional practice, and its effects on employability – so-called "Twenty-first century graduateness" for example - in the pedagogic literature, covered in Clark and Andrews.[11] My approach to enhancement was however more direct: I worked backwards from professional engineering design competence. The design strand was conceived to enhance employability by giving Nottingham students the practical professional design skills which most chemical engineering graduates lack.

I compared the Year 3 design projects with the quality of what early careers engineers produce, and identified key shortcomings. I tracked these shortcomings to their sources by talking to students, analysing course documentation and interviewing module conveners across all three university campuses (UK, Malaysia and China).

The problematic areas could be placed into five categories. There were areas which had formerly been taught but had been dropped because there were no engineers to teach them, such as plant layout and drawing skills. There were skills academia did not teach because academics did not know that engineers had them, such as how we approximate, estimate, and use intuition. There were also subjects taught in academia which are not what engineers do, such as working from first principles or primary research literature (as professional researchers would). There were areas of knowledge that everyone assumed someone else was teaching the students, such as mechanical design. Finally, there were areas which were thought mere "training", beneath the dignity of university educators, such as qualitative knowledge of equipment types. Most notably, academia does not teach any systematic design methodology.

Students did not undertake academic design exercises in my modules; rather every design project was a real project from my professional experience, or that of a visiting practitioner. Students were given the real documents which a professional engineer is given to undertake a design, and required to produce the same documents which that engineer would produce. This is a simple and direct way to avoid assessment drift - losing important aspects of the exercise via simplification. The students found this daunting at first, but so did I when I first saw such documentation in a work setting. They adapted very quickly, and proved to be capable of far more than many would expect.

Nottingham achieved a jump from 65% to 95% in student satisfaction, and the introduction of the design strand was quoted by students as a key factor in this improvement.

I learned to be an engineer in professional practice by designing plants, and interacting with more senior engineers in reviewing these designs. My teaching approach brings this into academia. Students design things I have designed, and I play the role of those senior engineers who shaped my own development as a professional engineer.

I recruited a number of fellow professional engineers to join me in playing the senior engineer role starting in year two of the three-year design strand, providing them with support in the administrative and pedagogic aspects of their teaching.

They were not fulfilling the all-too-common role of visiting practitioners in engineering courses, of providing some amusing anecdotes for the students, which play no part in the assessed content of the course. To quote a colleague, *"Industrial input is a valued optional extra. Most practitioners are great at telling tales, but can't be relied on providing the, yes, scientific backbone that differentiates a good graduate from a plant operator, technician or draftsman."* Our visitors from practice are, like me, engineers who have designed a given plant, offering the students an opportunity to design that same plant for themselves as the assessment of the course.

Since I am teaching an art, I consider the ideal teaching method to be a practice/ feedback loop, with as short a time between assessment submission, feedback, and the next attempt at practice as possible. It seemed to me that this was how I learned the things I now teach, though I did not learn them in university. I follow the principles of good feedback set out by Nicol & Macfarlane-Dick (2006).[14] Most importantly, I offer clear feedback on how to perform better next time, and each assignment comes with a very clear explanation of how the assignment is to be marked.

My students designed four complete plants by the end of year one. They designed three more in year two, before undertaking a year 3 design project. Mastery takes practice, but most universities do not require their students to design a complete plant before year 3. Feedback from employers was that my year two students were better practical engineers than other universities' graduates.

Summary Results

Nottingham underwent a massive improvement in employer reputation and employability, and moved from 16th-5th in THE Rankings in three years. NSS satisfaction scores improved from 67%-95% NSS. All improvements were reportedly based on enhanced realism and employability.

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Engineering without maths or physics: A threat to the development of engineering capital?

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Background

Starting with the question *'Should maths and physics qualifications be mandatory for entrance onto undergraduate engineering programmes?'*, this discussion paper is underpinned by a somewhat reluctantly acknowledged 'pedagogical truth', the fact that many students enrolled on engineering programmes arrive at university totally unprepared to study maths, physics and engineering at degree level. The reasons for such a lack of preparedness are complex and vary in nature from reported deficiencies in the content and focus of the school maths and science curricula[1], to inappropriate pedagogical approaches adopted in schools which, in 'spoon-feeding' students, have promoted a generation of highly dependent learners, unprepared and ill-equipped for university.[2]

Other, less tangible factors suggest the fact that many new undergraduates are simply not equipped with the high levels of social and educational 'capital' needed to succeed at university.[3] Indeed, outside the Russell Group, many young people enter Higher Education with relatively low *a priori* experiences and few transferable study and life skills. Anecdotal observations of class discussions in a non-Russell Group university during the first few weeks of term suggests that many new engineering students have little idea of what engineering entails. Few perceive engineering from a socio-scientific perspective and even less appreciate its applied nature. Furthermore, many new students within such a setting are simply unable to articulate why they chose to study engineering.

Whilst a small minority of students have enjoyed life-enriching experiences which have sparked in them a desire to study engineering, such as frequent visits to engineering or science places of interest or participating in STEM clubs at school, the majority of students from state school backgrounds have not had such privileges, certainly not ones that have been sustained throughout their primary and secondary education. Such students ontology and epistemology reflects school based learning only, meaning that, despite reported inadequacies, GCE 'A' levels in maths and physics are vital pedagogic tools in preparing students for university engineering study as the majority simply don't possess any 'engineering capital' when they arrive at university.

So why is this a problem?

Contemporary society faces unprecedented challenges in terms of the world around us. As natural resources diminish and global challenges such as climate change, poverty and sustainability grow, so the need for universities to produce the critical thinking problem-solvers of tomorrow becomes more pressing. Whatever the challenge, there can be little argument that engineering has a pivotal role to play in building a secure future for all of us. Knowledge of, and experience in, maths and physics are both integral to this as they underpin engineering in the same way that engineering underpins society. Yet for over three decades many pre-university students have 'shied' away from studying maths and physics at 'A' level[4], a fact that seems to have negatively impacted the numbers seeking to study engineering at university.

Table 1 below gives the HESA data for the academic year 2014-15.[5] This data reveals that Business Studies continues to be the most popular subject with over twice as many graduates as Engineering.

Subject	Undergraduate degrees awarded 2014-15
Engineering and Technology	25,435
Medicine and subjects allied to Medicine	52,965
Business Studies	59,725

Table 1: The Numbers of Students Graduating from UK Universities in 2014-15 in 3 key subject areas (adapted from HESA (2016))

Having identified that fewer students are entering Engineering and Technology based programmes than Medicine or Business Studies, the question as to why this is the case is raised. Moreover, arguments that the requirement for students to possess GCE 'A' levels in maths and/or science as a pre-requisite to studying Engineering could be putting many prospective students off, appears to be disproved. Indeed, many Medical and Business Studies programmes require maths and/or science 'A' levels (indeed, science is mandatory for the majority of medical programmes).

Discussion

So do prospective engineering students need 'A' level maths and science?

Some Russell Group universities have removed the requirement for GCE 'A' levels in maths and/or physics from their engineering programme entrance requirements. Whilst such institutions tend to attract those students who already possess high levels of social and thus engineering capital, for the majority of HEIs in the UK, such a move would not be feasible as the majority rely on learning from school to provide them with the building blocks for university level study by their students. Additionally, having established that it may not be the requirement for 'A' level maths and physics that is causing young people to turn away from engineering, the suggestion that the subjects should be removed as pre-requisite qualifications on a national basis becomes somewhat baseless. To do so would result in those students from lower socio-economic groups, who don't have the social capital to catch up once they're at university, being significantly disadvantaged. Any such moves to remove the requirement for maths/physics would also mean that the majority of students would find themselves incurring more debt as engineering courses would have to expand in length so as to accommodate the need to study basic maths and physics – resulting in a 'Foundation Year' becoming the norm.

The fact is that a majority of young people simply don't possess sufficient engineering capital prior to studying engineering at University. Indicative of the lack of engineering capital is reflected in the argument that for many young people engineering is an unknown quantity. Removing maths and physics from the pre-requisite qualifications to study engineering won't change this, it will instead simply act to reduce the pool of potential students able to succeed. The focus should be on the contextualization of maths and physics both at 'A' level and within universities such that

application and concept understanding are central to the learning and teaching. This approach should be engaging, flexible and one that allows for experimentation, where poor solutions promote greater curiosity.

Another solution to the problem is to raise young people's engineering capital from early years. For this to be achieved, engineering needs to become part of a child's everyday life, vocabulary and learning experiences. As such it should be built into the school curriculum right from the outset. After School STEM Clubs have a place, yet they only capture a minority of children. If Engineering is to compete on an equal footing with Medicine and Business in the drive to attract students, then there needs to be a combined effort to make this happen. University outreach has a role to play by providing academic staff to act as role models and to contextualize maths and physics in their activities with learners. Additionally, engineering industry also has to accept some responsibility for providing the means by which school children may acquire engineering capital (possibly by sponsoring STEM experiences or providing volunteers to work with children in schools). With sound evaluation, a coherency with the school curriculum and sustainability over time, there is potential for success in developing future engineering talent.

Conclusions

In conclusion, moves by some institutions to remove the maths and/or physics entry requirements for undergraduate level engineering study can only act to further promote and maintain extant social class barriers in engineering, whilst doing nothing to address the root causes of the problem. Any such move would not increase participation in engineering education, but would instead cause irrevocable damage to both students, who would inevitably fail, and Higher Education Institutions, who would be required to pick up the pieces. At a time when student success is front and centre in university thinking, it is essential that all that can be done to ensure the success of students in engineering education is being explored. This will require coherent and meaningful change across the transition points in line with the suggestions presented in this paper.

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Improving the employment prospects of graduate engineers through an SME placement bursary scheme:

A successful collaboration between the Institute of Mechanical Engineers and Aston University

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Abstract

This paper explores the effect of a pilot placement bursary scheme on its key participants; SME engineering employers and undergraduate Mechanical Engineering students. It considers the impact of the scheme from the perspective of the current skills shortage in this sector, and prevailing intelligence on graduate work readiness. We would like to use this success story to encourage and inspire other Professional Engineering Institutions to collaborate with us to connect more SMEs with student engineers in the West Midlands region.

Keywords: Graduate employability, integrated placements, bursary scheme, SMEs, Professional Engineering Institutes (PEIs), Higher Education Providers (HEPs).

Introduction

Within the context of a widely-reported skills shortage in the engineering sector, there has been a 4.7% growth of applicants to HE engineering courses since 2014[6], at Aston University the number of students completing Mechanical Engineering degrees increasing by 130% over the last five years. However, an analysis of the employment destinations of recent engineering graduates reveals that many choose to pursue alternative career paths on graduation; the Perkins' Review reported that less than 70% of male engineering and technology graduates from 2011 made the transition into an engineering field[2] (p37). This is not surprising as the knowledge industries, such as professional services, are growing[3] (p47), and the vast majority of their graduate roles are open to all degree disciplines and actively seek the types of skills that graduate engineers possess e.g. application of numeracy and problem solving. Also more significant is that some engineering graduates remain unemployed or underemployed at this time, a paradox that employability skills may help us explain (p183).[1]

Increasing the volume of engineering graduates is not the sole solution because employers report that across the sector graduates are not 'work ready', and lack the soft skills that enable their discipline-based knowledge to be applied to the workplace effectively. A prominent theme of the Wakeham Review was the value employers placed on these skills, supported by "a large body of evidence pointing towards continued employer dissatisfaction with graduates in this respect" (p3).[4] Many reasons have been suggested for this including, the extension of the period of transition to work, and the decline of student part-time working[1] (p64). Whatever the casual factors, this lack of professional capital amongst millennials is now perceived as a real barrier to recruitment and a key priority for Higher Education Providers (HEPs).

With the marketplace for graduate engineers highly competitive, it is not surprising that many small and medium-sized enterprises report difficulties recruiting graduates when competing with the programmes offered by their larger compatriots. Within the West Midlands region micro businesses (up to 9 employees) account for 76% of all registered engineering enterprises, and levels of employment are now growing after a longer period of decline. With the region delivering almost 40% of total engineering turnover[1] SMEs are crucial to the future economy as it is currently envisioned. But with difficultly accessing a skilled workforce will they struggle to grow?

This paper explores the impact of an SME placement bursary scheme on these issues, a partnership between the iMechE and Aston University during the academic years 2014-2015 and 2015-2016.

Levelling the field for SMEs

In 2013 the Perkins Review stated that employers had a powerful role in helping secure engineers, and that the challenge was therefore "for employers to engage more effectively across all HE institutions by providing more students with industrial placements"[2] (p41).

The traditional industrial placement is the year in industry model; undergraduate students spending the third year of their degree working in their target sector, before returning to university to complete their studies. The selection processes for these placement opportunities is now becoming increasingly difficult to distinguish from the graduate recruitment process, with competition for places high and not enough to go around. This is partly because the majority of placements are offered by organisations whose brand and infrastructure (size, location and reward) appeals to those students who have chosen to invest in their employability and extended their period of study to four years. But what of those students who fail to secure these placements, and the huge number of SME engineering employers who struggle to compete in this difficult market?

One of the recommendations of the Perkins Review was that the engineering community coordinate engagement with university students to raise awareness of the range of opportunities within both large and small employers [2 p.42]. The IMechE SME placement bursary scheme was initially piloted within two Universities in response to this recommendation; Aston University was chosen because of its successful track record in the organisation of year-long industrial placements.

The goal was to encourage participation from small and medium sized organisations who had never previously engaged in hosting student work experience, and secure twenty-four new SME placements over two academic years. The challenge was to seek out those companies who did not traditionally engage with universities or have a presence on campus, and support them to host a student placement by providing assistance with recruitment and funding to the value of a £2k bursary.

The project successfully generated twenty-four new placements with SMEs that had not previously engaged with Aston University, increasing the University's engagement with engineering SMEs by 75%, and beginning the process of promoting this employment sector as a graduate destination of choice.

The value of the integrated Work Placement

The value of the integrated Work Placement year to the employability of undergraduate students is consistently well documented[5 6], which is why integrated placements are the cornerstone of Aston University's employability strategy. Aston are currently 4th in the table of UK Universities placement activity (HESA), achieved through institutional commitment and a coordinated effort that begins even before a student arrives. Work towards the goal of achieving 100% of students undertaking a placement is also bearing fruit - Aston University achieved 18th position in the 2016 *Sunday Times* measure of graduate employability published in September 2016.

Experience has shown us that early employer engagement extends the degree education past the application of discipline-related skills, and into the development of work-related competencies (soft skills) and 'professional' behaviours. We see evidence of this change in the quality of transition documents e.g. CVs and applications, viewed in the Careers+Placements department from final year students who have completed a placement. The significance of the placement experience to the process of articulating the self is in the richness of the career stories generated, which are supported by evidence that can bring the learning to life.

If the placement year develops those soft skills and behaviours that employers seek when recruiting graduates, it also impacts final year academic performance. Research undertaken at Aston University by Helen Higson has shown that placements have a positive and significant impact on academic performance[6] (p13). Students return from placement with a different attitude toward their studies, one that is critically important for their successful transition into the world of work[3] (p48).

Finally, could an integrated placement influence those students who drift away from the engineering profession at graduation and pursue an alternative career? The graduate workplace is virtually unknown to students; part time and summer jobs offering only limited skill development and an understanding of the responsibility for being paid. When students reach their final year of study and the process of graduate recruitment begins they are showered with opportunities that compete for their attention; particularly for those students with skillsets in high demand. However, those who have completed a placement have first-hand knowledge and experience on which to base their career decisions, because they are already engaged with industry and have begun their professional career journey.

Summary and moving forward

This paper has shared the benefits of the IMechE SME placement bursary scheme for each of its stakeholders; employers receiving help to engage with the next generation of engineers, and students developing their soft skills and beginning their professional careers. For the IMechE and Aston University this has been a good example of the collaborative work undertaken between PEIs and HEPs to support the engineering sector, which also includes careers and curriculum-based activities, and guidance on course development. But where now?

At Aston University we would like to use this success story to encourage and inspire other PEIs to collaborate with this initiative. Through this pilot we have developed a model of engagement with engineering employers that works, and we would like to expand this further to engage more SMEs located in the West Midlands region.

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A sociological analysis of engineering education

K. Moffat

Introduction

This paper discusses ongoing research that I am conducting towards a PhD in the sociology of education. I am conducting this social science research part time, while also working full time as a course director for an industry focussed engineering degree programme, an appointment that followed around twenty years in industry. I am deliberately writing this paper in the first person in order to make it clear that some of what follows, particularly in the first part of this paper, is based on my subjective personal experience. This is part of what is known in sociology as reflexivity[1] and is an essential part of subjective, qualitative research, requiring the researcher to become aware of their subjective position in relation to the data, and also to ensure that the reader is aware of the subjective elements. This is particularly relevant to the autoethnographic method[2] that I have used to capture my personal experience of lifelong learning and continuing professional development. Just because research is qualitative and subjective, does not exempt it from scrutiny and quality control, and while the traditional measures of reliability, validity and objectivity cannot usefully be applied to autoethnography[3], these can be reconceptualised as trustworthiness, credibility, conformability, dependability and transferability/usefulness[4 5], and measures including interviews and extant literature were utilised as part of this process. In addition to this, the subjective autoethnographical elements of the earlier part of my study, are complimented by the later Bourdieusian sociological analysis of engineering education discussed in the latter sections of this paper.

Autoethnography and epistemological epiphanies

Ethnography is an established method in social science which is related to anthropology, and involves the observation of cultural groups in society. It follows that the addition of auto, from autobiography, makes autoethnography an observation from the perspective of the self, and this method has been used in many fields to observe and analyse professional practice. Autoethnography can take many forms, but my methodology was influenced by an analytic form of autoethnography first proposed by Anderson[6], because I was interested in identifying issues of learning from the perspective of the learner, and relating these to existing literature and practice. My methodology also developed a grounded theory approach[7 8 9], which in practice meant that I wrote the autoethnography first without preconceptions, and only afterwards conducted a thematic analysis and literature survey to narrow the field of study and connect the data to the existing literature. I had originally expected this analysis to focus on education in general, perhaps related to why I had not been academically successful until later in life, but a number of aspects of my experience pointed towards what I would later refer to as a disconnect between engineering education and practice. This disconnect had first become apparent when studying underpinning concepts in ontology and epistemology at the beginning of the PhD. Ontology and epistemology are related to the way in which an individual views the world, and whether one is likely to take an objective, quantitative approach to knowledge, or a subjective, qualitative approach. I reflected that while I saw engineering academia as being very quantitative, objective and theoretical, I felt that conversely my experience of engineering practice was often qualitative, subjective and applied.

I also reflected on my disengagement with secondary school mathematics, which meant that I would not have been qualified for, or interested in, a profession that was advertised as being intensely mathematical. When I later entered the profession through a practical route, and career progression required me to complete an engineering degree, I was surprised to find, given my existing experience in engineering related roles, that what I was studying was practically an applied mathematics degree. The level of mathematics required was extremely demotivating, and from my experience seemed largely irrelevant to practice, but I persisted and completed an MEng degree. The fact that I gained a distinction demonstrates that I eventually mastered the calculus and complex numbers, but after graduating I immediately started to lose this knowledge because I could find little use for it as a practicing engineer. I wondered why there was so much emphasis on handwritten, classical mathematics, when in my experience of engineering the mathematical work was almost always done using spreadsheet programmes or specialised engineering software.

Literature survey

Engineering is a very broad and varied field, and clearly I could not generalise from my experience alone, but the autoethnography had raised some serious questions that merited a review of existing literature. I was surprised to find so many examples of industry and institutional sources complaining about the pervasion of classical forms of mathematics in engineering degrees, with some practitioners going as far as to state that their University mathematics was a 'waste of time'.[10] Mathematics researchers had also explored this topic, and as far back as 1989 some had suggested that the level of mathematics that students were being required to obtain, was 'completely unnecessary'[11] and out of step with the way that engineers use mathematics in practice. Mathematics researchers Kent and Noss chose to study engineering because they expected to find a 'mathematically-rich professional practice', and were instead surprised when their survey returned comments such as:

> *Once you've left university you don't use the maths you learnt there, 'squared' or 'cubed' is the most complex thing you do.*
>
> *For the vast majority of the engineers in this firm, an awful lot of the mathematics they were taught, I won't say learnt, doesn't surface again.*
>
> *There is a whole lot of maths in what we do that we don't need to think about really, because other people have done it for us*[12]

Another mathematics researcher Julie Gainsburg, highlighted the 'mismatch between the mathematics-oriented version of engineering design promulgated by schools and textbooks and design as practiced in the field'.[13] While these challenges to engineering education were long standing and well documented, they appeared to have had little impact on engineering pedagogies, and most engineering academics appeared to be either unaware or unwilling to engage with the issue. In fact studies had found that engineering academics continued to stress 'the absolute importance of high levels of mathematical competence, some with the implicit meaning that this competence is necessary for students to succeed in their particular advanced course.[10] As the

disconnect between engineering education and practice was already established in published literature, my ongoing research is now focussed, from a sociological perspective, on how such a situation is maintained.

Bourdieusian analysis

Pierre Bourdieu developed a framework of sociological theories that have since been widely used in education[14], and in studies of professional practice[15 16], but his concepts have received little attention in engineering education research. It has been suggested that this is because engineering education researchers tend to be primarily trained and focussed on technical and scientific knowledge[17], while the concepts that underpin Bourdieu's theories are drawn from philosophy, anthropology and sociology. On the other hand, sociological researchers are unlikely to have the required background knowledge and connections to the engineering profession. An in depth discussion of Bourdieusian concepts and methods are well beyond the scope of this paper, but I offer a very high level description of the concepts that are critical to my analysis of engineering education; those of capital, habitus, fields and doxa. The concept of economic capital and its relationship to Marxist economic theory are well known, but Bourdieu adds social capital, or who you know, and cultural capital, or what you know, to give a more complete way to describe power and society. Of these, cultural capital is arguably the most complex concept and Bourdieu stated that this can be embodied, objectified, or institutionalised.[18] Objectified capital can include art and fine wines, and is less relevant to this discussion, but embodied and institutional capital could respectively represent knowledge that an individual has internalised and knowledge that is represented by an academic qualification. Bourdieu argues that these various forms of capital, only have value within a specific field of power, so for example an engineering degree has little value in the field of nursing, but is a valuable currency in fields related to engineering. Sociological analysis through conceptualising a part of society as a field, is in some way analogous to systems engineering, and allows an in depth analysis of how exchanges of capital between individuals within that field affect both the field and the habitus of its members. Habitus is a vague and complex concept, but for the purposes of this paper can considered to be the window through which an individual views the world, and is the key concept that I refer to in my analysis. Finally, doxa, and doxic knowledge can be considered to be knowledge that is assumed, and therefore goes unchallenged.

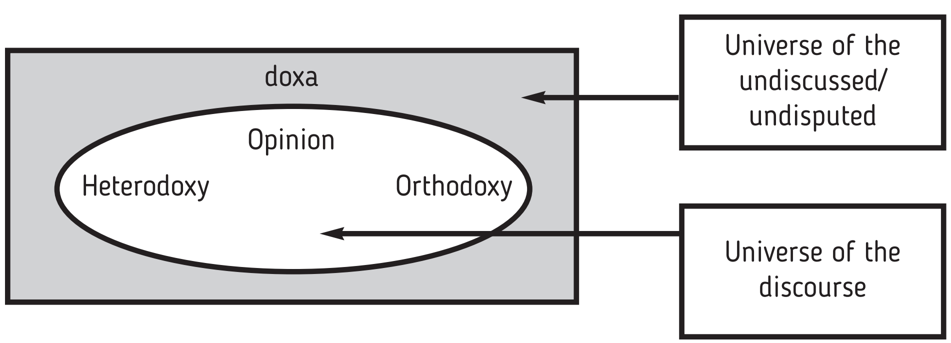

Figure 1: doxa

A doxic belief is an unquestioning belief, and part of my research explores whether engineering academics have a *doxic* belief that mathematics and engineering are inextricably linked, and that there is no other way to practice or understand engineering concepts. I use the term doxa here because I am suggesting that that this is an unquestioned belief, rather than an orthodoxy, because for many engineering academics their habitus will not have exposed them to an alternative view. According to Bourdieu, habitus is the embodied history of the individual and therefore is inextricably linked to the field in which that habitus was formed. The habitus of the engineering academic is largely formed within the field of engineering academia, and I argue that in many ways this field is disconnected from engineering practice. I have begun to conceptualise this in the figure below, where I also present engineering academia is part of a larger field of scientific research, and engineering practice as part of the larger field of industry and commerce.

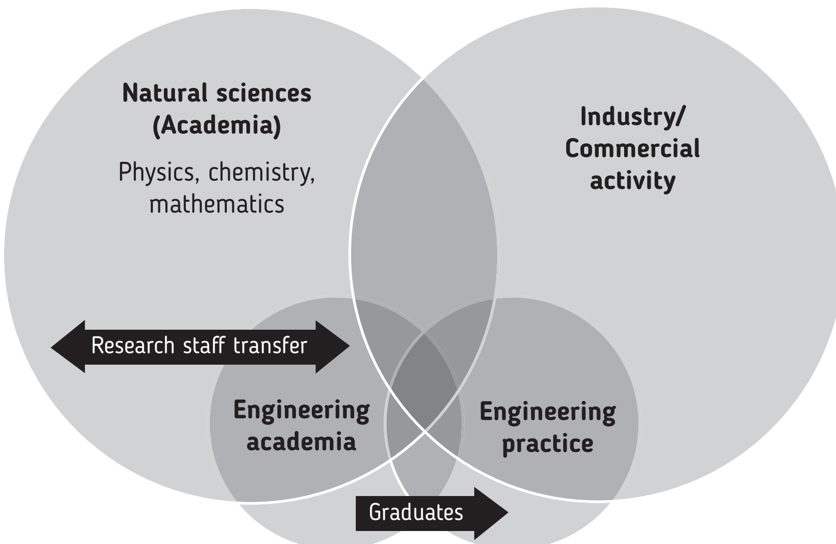

Figure 2: Engineering conceptualised as Bourdieusian fields

Arguably habitus not only informs what is taught, but also how it is taught, and what is seen as important. If an academic believes that mathematics and science are fundamental to engineering, they may imply that 'high-status analytical courses are superior' to those which 'encourage the student to develop an intuitive 'feel" for the 'complexity of engineering practice in the real world'.[19] The concept of habitus can be used to explore why engineering academics might have a different understanding of engineering to practitioners, but as there is a deterministic element to habitus, it also explains why it is difficult to implement change.

Conclusions

It is beyond the scope of this paper to fully explain the concepts underpinning a Bourdieusian analysis, or to offer more than a cursory outline of the methods and data collection that have led me to my contention; that there is a serious *disconnect between engineering education and practice*. However, I would argue that the complexity of a Bourdieusian sociological analysis, provides a way to explore how social, economic and cultural factors combine to construct the fields of engineering academia and practice, and the habitus of the individuals within. If individuals can understand how their habitus has been formed, it can help them to understand their own actions and how their world view has been developed. For engineering education this has broad implications, because if the habitus of an engineering academic is significantly different from a practicing engineer, then their understanding of engineering is also likely to be different. Understanding how these differences are formed may be the first step towards resolving the *disconnect between engineering education and practice*.

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Teaching manufacturing for the 21st Century

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Introduction

The provision of workshop practice within university degree courses varies both in the learning objectives and the significance attached to it. UK-SPEC[1] requires engineering graduates to be able to apply engineering theory, including "practical and laboratory skills" but is wide open to interpretation. In this paper, a novel approach to designing a workshop practice exercise is described.

Most traditional engineering universities have a machine shop, where technicians are employed to manufacture parts for research. Such facilities have also served, for a small proportion of their time, as a teaching space. More recently, with an increased focus on teaching, a number of universities have introduced dedicated student workshops, where students are taught traditional skills such as turning, milling and welding.[2 3] However, such exercises tend to focus on practical training, with assessment of manufacturing ability, rather than on reinforcing manufacturing theory

In September 2015, The University of Sheffield's brand new engineering building, The Diamond, opened. This provided the opportunity for a new first-year manufacturing module to be designed in conjunction with the construction of brand-new, large-scale manufacturing facilities. Hands-on workshop skills courses exist in most mechanical engineering departments but tend to be stand-alone exercises, and designed around existing equipment capabilities and eye-catching projects. For example, previous projects at Sheffield have included a vice and a Stirling engine, consisting almost entirely of traditional metalworking. While such exercises clearly provided the students with a beneficial experience, they take little or no account of recent advances in education methods - learning outcomes are either not defined or not constructively aligned with the activity or assessment. In this new module, the learning outcomes were first defined, and the desirable manufacturing processes selected, before a product, method and assessment were designed to achieve the intended outcomes.

Defining the Learning Objectives

There can be a range of learning outcomes (LOs) from practical manufacturing classes, including: development of psychomotor skills; understanding of how manufacturing processes work; appreciation of the pros and cons of available manufacturing methods; and appreciation of the impact of design on cost and manufacturing time.

While all of the above LOs are desirable across a programme, it was considered that the primary aim for this module was for engineers to have an appreciation of the range of manufacturing processes available (both modern and traditional), their advantages and limitations. The learning outcomes were therefore defined as follows:

By the end of the course, students should be able to:

1. Use a range of manual tools and machinery to manufacture parts from drawings

2. Perform a range of basic turning operations on a manual lathe.
3. Identify the advantages and drawbacks of common manufacturing methods
4. Discuss how the design process is affected by manufacturing considerations such as material cost, time and geometric limitations

This balance of breadth (by covering a wide range of equipment) and depth (by spending a considerable amount of time on the lathe, learning a range of processes and experiencing the challenges involved) was felt to give the best appreciation in a relatively short course.

Designing the activity

The activity was run alongside an existing lecture-based module ('Engineering Techniques and Manufacturing Technology') in which students were taught in traditional lectures and assessed in an exam on the mechanics of various manufacturing processes. A survey was carried out of the processes covered in the lectures, which included turning, milling, casting, sheet metal work, 3D-printing, laser cutting, vacuum forming and fastenings. A team of experienced workshop technicians and academics came together to design a product that could be manufactured using as many of these processes as possible. From a number of possibilities put forward, a miniature gyroscopic single-wheeled vehicle was selected. Various versions of miniature gyroscopic vehicles exist[4,5], using recycled household objects, and it was clear that the product offered the possibility of a range of materials and manufacturing methods being used, as well as an engaging and satisfying experience for the students. The basic elements of the concept (a vehicle containing a motorised flywheel linked by friction gearing to a single drive wheel that runs on a monorail) were incorporated into a new design that utilised all of the above processes as well as basic workshop skills such as drilling and bandsawing. A model, produced in SolidWorks (Dassault Systemes, Paris), a computer-aided design (CAD) package, is shown in Figure 1.

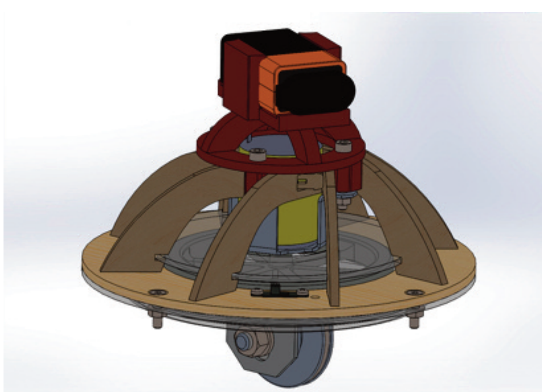

Figure 1. CAD model of the Gyrocar

It was designed, where possible, to be manufactured from raw materials, so as to give students an understanding of the whole manufacturing process, and to be cost-effective for large numbers of students. An additional constraint was the effective utilisation of the equipment. Throughout the academic year, approximately 600 students completed the course in classes of up to 30, with

each student having 24.5 hours workshop time split over seven sessions. In order to avoid bottlenecks on the equipment, individual schedules were designed for students, to move them around the workshop as efficiently as possible. This was incorporated into the learning so that students understood the need for process design in a production unit, in order to maximise output and hence reduce costs. Students worked from a set of manufacturing drawings, which helped them to understand the process of communication from designer to fabricator and the importance of clarity of intent.

Figure 2. Students working on the Gyrocar project

Assessment

For the purposes of accreditation, the practical exercise was pass/fail. Students were assessed on the number of processes completed in the allotted time (LO1, LO2). Although there was sufficient difficulty in the manufacture to make it interesting, all students who attended all sessions were able to pass the course. The higher level LOs concerning understanding of the impact of process selection on design are more difficult to assess in a practical class, and it is felt that these are often neglected. However, by pairing the practical activity with an academic module, it was possible to assess these learning outcomes in other ways. It was considered that the practical classes should reinforce and expand the learning from the lecture course, so that Learning Outcome 3 could be well assessed in the exam. Additionally, students were required to submit a report on the manufacturing process where they were asked to consider how they might improve the manufacturing process and reduce costs. This allowed assessment of the final learning outcome (LO4).

Further development

In order to determine the impact of the work, it is intended to gather feedback from students in the next academic session. Student feedback and results will be analysed to determine whether the new curriculum has improved engagement and understanding of manufacturing processes.

While the practical learning outcomes of this module were fairly structured, focussing on experiencing manufacturing processes, it is intended to develop the wider curriculum so that programme-level learning outcomes can include being able to design and manufacture prototypes to meet a specific brief. The skills and knowledge acquired in the first year manufacturing course will be used in a second-year group design project, bridging the gap to existing individual projects later in the course, and will form part of a more integrated approach to design and manufacturing, linking the teaching of CAD and sketching, design methodologies, manufacturing, and laboratory testing across the degree programme.

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Enhancing public and student understanding of engineering via MOOCs

Eann Patterson, *AA Griffiths Chair of Structural Materials and Mechanics & University Learning and Teaching Fellow, University of Liverpool*

The concept of teaching introductory engineering using the Everyday Engineering Examples set with the framework of the 5E lesson plans[1] was developed in the USA as part of an NSF grant on 'Enhancing Diversity in the Undergraduate Mechanical Engineering Population through Curriculum Change' during the first decade of this century. The use of Everyday Engineering Examples provides a context for explaining engineering principles that is familiar to a wider audience than the traditional examples found in many textbooks. This is important because a lack of familiarity may induce students to panic about the context and fail to listen[2] and because the perceived usefulness of learning influences students' motivation.[3] The approach is becoming widely used in the USA where more than seventy engineering schools have participated in the ENGAGE project, which was an exploitation and dissemination programme funded by the NSF to promote the approach.[4] As part of this programme between 2008 and 2011, more than fifty lesson plans were published in a series of booklets covering dynamics, fluid mechanics, mechanics of solids and thermodynamics. These lesson plans are now available on-line on the ENGAGE website[4] and RealizeEngineering blog.[5]

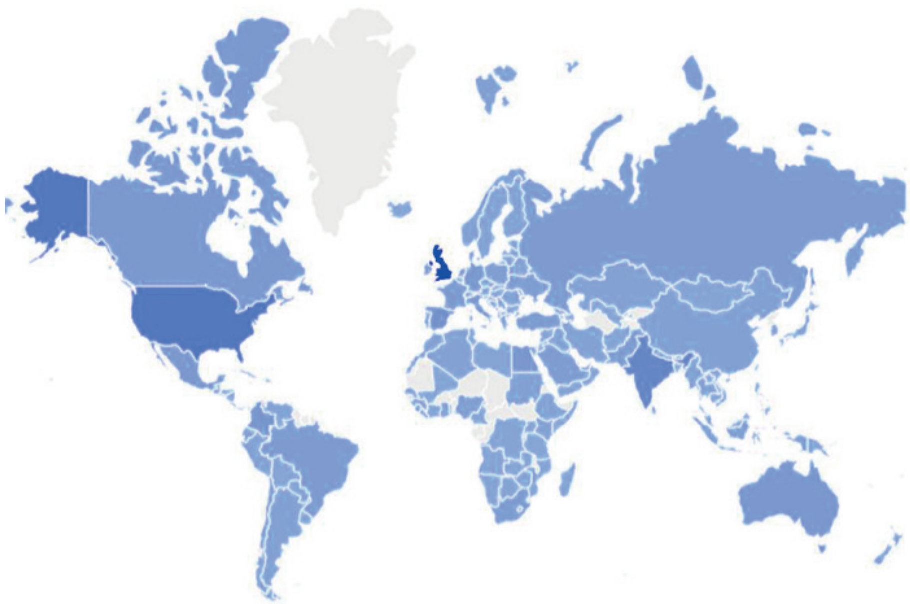

Figure 1: Distribution of learners on recent MOOC on Energy: Thermodynamics in Everyday Life [7]

Studies have shown that everyday engineering examples significantly raise students' learning, regardless of the level of difficulty embedded in the example.[6] Recently the combination of the 5E lesson structure and Everyday Engineering Examples has been extended to a Massive Open Online Course (MOOC) entitled Energy! Thermodynamics in Everyday Life[7], which has attracted thousands of learners in more than 130 countries (see Figure 1) and with many different backgrounds. The syllabus for the MOOC was the same as for the corresponding first-year undergraduate module in the School of Engineering at the University of Liverpool. The MOOC was synchronised with the delivery of the same material to more than 300 undergraduates in Liverpool over a five-week period in 2015/16.

A number of innovations where introduced in the MOOC, including planning of clusters of steps in the MOOC using the 5E approach to lesson planning, the use of practical exercises as 'homework assignments' and the deployment of Clear Screen Technology™ to present worked solutions to example problems. These innovative features, combined with a strong level of support for social learning, resulted in a relatively high completion rate for the MOOC (28%) with women making up one third of the population of fully participating learners who completed 80% or more of the seventy-five steps in the MOOC. A survey of these fully participating learners implied that the pedagogy enhanced their motivation, understanding and participation (see figure 2). Undergraduates made up 17% of the fully participating learners and about half of them (56%) would have considered the MOOC an acceptable replacement for lectures. So, this year (2016/17) a proportion of the traditional lectures on campus have been replaced by the MOOC. These developments appear to provide opportunities to democratise engineering higher education, to enhance public understanding of engineering science with the potential to attract more diverse applicant, and to offer innovative ways of communicating with undergraduate students that may broaden the attractiveness of undergraduate courses to a more diverse student population and provide different ways for them to learn.

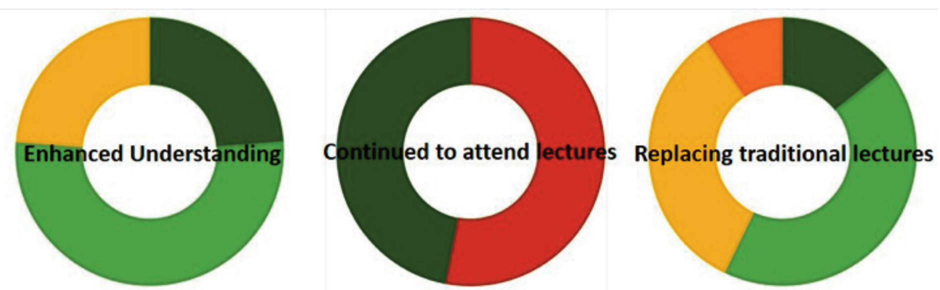

Figure 2: Survey results from fully-participating learners in MOOC using traffic lights colours to represent the data.

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The teaching of inclusive engineering

Dawn Bonfield MBE CEng, FICE, FIMMM, FWES, *Director, Towards Vision*

Introduction

The engineering profession has come a long way since the industrial days when engineering meant making something that worked, and seeing if you could improve it to a point where it also made money. Nowadays engineering also includes the additional considerations requiring engineers to ensure that their products are safe, ethical, sustainable, free from cyber vulnerability, and – more recently - inclusive. Inclusive engineering is a relatively new discipline which requires engineers to have a competence which ensures that not only are teams made up of a diverse range of members, who bring with them the diversity of thought that we need – which evidence has shown leads to more profitable, more productive and more innovative business, but also to ensure that the engineering solutions that they produce are equally inclusive of all considerations and viewpoints. A growing body of evidence points to ways in which getting inclusivity right has produced solutions that are better and more acceptable to the customer, and lead to a safer and healthier working environment.

The discipline of inclusivity, however, is one which – like all other competences – has to be taught, and has to be practiced, and teaching our next generation of engineer the value of diversity and inclusion at undergraduate level is a way of ensuring that our future engineers have the competences we require. This teaching of inclusivity should form part of a wider programme of introducing a Diversity and Inclusion Programme to an Engineering Department.

Teaching Inclusivity

To ensure that the competence of inclusivity is taught at degree level in engineering we must embed it into the requirements of UK SPEC, the specifications against which our engineers are taught and measured. And once embedded, we need to ensure that we train our accreditors in the requirements and the methods of seeking evidence to prove inclusivity.

Embedding inclusivity into engineering degree courses should be done in two ways. Firstly, 'Diversity and Inclusion' awareness modules for students, where the competences and behaviours are taught specifically and separately to the engineering content, and can be included throughout the course as discrete seminars, tutorials or workshops.

Secondly, inclusivity can be integrated into the content of the engineering curriculum, by way of example and case study. There are many opportunities to do this, and these can be expanded as students bring additional examples of their own. In both cases here the competence becomes learned and becomes part of the engineering mindset, instead of being an extra that gets forgotten as soon as the 'nudge' goes away.

The novelty of this approach, introducing inclusivity to students by means of relating it to the actual engineering they are studying, is that it becomes much more relevant, more intuitive, and more relatable to the students. They begin to understand that there are important safety, product and service design, productivity and financial sustainability improvements that can be made as a result of inclusive behaviours. They will be motivated to find ways of developing this competence, knowing that they are becoming better engineers delivering higher performance, and producing better solutions.

The following topics could form part of a taught module, and these would be built upon and tailored appropriately as the students near the end of their course, and progress towards employment.

Year 1	Year 2	Year 3+
Introduction to diversity and inclusion including diversity guidelines	Inclusive product design	Inclusive leadership
Inclusive behaviour	Current legislation, standards and codes of practice	Building the business case
Developing an inclusive culture	Inclusion as part of a safety critical culture	Inclusive recruitment
Unconscious bias and bias interrupters	Strength Based Diversity	Diversity & inclusion through procurement
Diversity lenses	Inclusive Engineering Tools and practices (BIM, Lean, TRIZ, Offsite Manufacturing, Factory re-engineering etc)	Improved productivity through inclusion
Global responsibility	Stereotypes versus archetypes	Branding and marketing
Positive action versus positive discrimination	Diversity benchmarking, measures and targets	Driving inclusiothrough the supply chain
Real examples of Inclusive Engineering	Real examples of Inclusive Engineering	Inclusion through business tools (strategy, policy, procedures and processes)
		Real examples of Inclusive Engineering

Wider Programme of Diversity and Inclusion

A number of other activities introduced within an Engineering Department will ensure that the teaching of inclusivity is not done in isolation, and that a broader level of diversity and a culture of inclusion exists.

Academic staff must also be aware of how inclusive teaching practices lead to a better departmental culture and improved outcomes for students (and teaching staff) from under-represented groups. This work will involve the engagement of students from under-represented groups before they even apply to the university, through visits and outreach activities, and ensuring that they are supported once at university. This work may also involve an examination of the entry level requirements, and the need to change teaching schedules in order to accommodate these students with different levels of skill. The following areas should feature in a strategic plan

to improve diversity and inclusion in an engineering faculty:

- **Integration of inclusion examples into taught curriculum**
- **Inclusive teaching**
- **Review of entry level requirements and relevant adjustments of teaching schedules**
- **Athena Swan Award progression**
- **Benchmark of culture and target setting**
- **Widening participation**
- **Student support groups**
- **Mentoring support**
- **Student feedback and reporting mechanisms**
- **Staff support and progression plans**
- **Outreach and community engagement**
- **Communicating diversity and inclusion messages**

Summary

So in summary, to improve diversity and inclusion in engineering in a more integrated and sustained way it is necessary to introduce the teaching of inclusivity at undergraduate level, and to link it to the engineering curriculum itself, in conjunction with UK SPEC. For maximum benefit, this work should complement simultaneous cross departmental activity designed to produce a culture change within the department.

The learning and teaching of engineering mathematics:

Is it fit for purpose in the 21st Century?

Michael Peters and Robin Clark, *Aston University*

Context

With the advent of industrialisation, employers required workers who had basic literacy and numeracy skills and were trained to obey orders. To address this situation, Parliament decided that all children should be educated and passed the 1870 Elementary Education Act (The Forster Act). This act implemented the recommendations of the 1861 Newcastle Report which urged the government to provide 'sound and cheap' schooling for children between the ages of 5 and 13.[1]

Since these early days engineering has developed to such an extent that contemporary employers require engineers who know how to perform tasks, have the necessary technical knowledge and, importantly, know when and how to apply their knowledge and skills to resolve a particular problem. Engineering is not a straightforward linear process, it is full of ambiguity and uncertainty where the engineer has to continually balance and negotiate challenging situations.

Figure 1 depicts the continuum of engineering skills required by a modern engineer.

Figure 1, Engineering Skills Continuum.

This continuum represents the relationship between the skills an engineer will require to solve complex problems. Each problem is unique, each one will require a different level of technical skill and knowledge and a different level of personal/interactional skills.

The inference from the above is that today's paradigm of engineering education with it's over reliance upon procedural mathematics, is outdated and not fit for purpose. In order to support the changed landscape it is vital that Engineering Habits of Mind[2] are nurtured.

Study

This was the motivation behind introducing a PBL (Problem Based Learning) mathematics class to first year undergraduate engineering students.

The cohort (350 students) were put into groups with a maximum membership of six and told they needed to choose an open-ended, ill-formed task from a range of options available to them. The tasks included ones appropriate to each of the engineering disciplines represented ie. Mechanical, Electrical and Chemical Engineering. An example of a task is shown in Appendix 1.

The students were given talks on problem solving and working as a team with documentation provided to support these skills. These aspects were included in the course as a consequence of the feedback given and evaluation by the previous cohort. It had been assumed with the previous cohort that they would have experienced some form of problem solving and would also be familiar with working in groups. This was proven to be untrue.

The tasks were assigned challenge levels ranging from a Level 1, where the initial tasks provided some guidance to a Level 3 where very little guidance was given. For the task shown in Appendix 1, the initial tasks were designed to provide the students with a starting point. The students were also told that provided they produced a resolution beyond what was asked for on the task sheet, they would be able to extend the possible marks to 100 from 80. They were not given any help on how to extend the task which was left for them to decide within their groups.

The assessment was designed to assess their problem solving skills, their ability to work as a team and their knowledge and skills in presenting a resolution. It was not designed to test their mathematics per se or their skills with Matlab. The tasks were to be assessed by a poster presentation on a task which they chose to submit. This form of assessment was decided upon since it provided the groups with the opportunity to gain valuable skills and knowledge in how to present a resolution in an appealing, succinct manner. The posters would be assessed by staff from the appropriate disciplines who were asked to make judgements on the presentation aspects and the technical content. The groups were informed of who the assessors were and told to expect in-depth questioning regarding their proposed resolution. The groups were also informed of the benefits of keeping a log-book to which they could refer to during the assessment process.

Evaluation by Module Leader

The module leader for this activity kept a field log of the activities of the groups each week. This field log kept a record of student responses to the weekly discussions held with the module leader.

Typical questions during the initial phases were around students asking for the equations etc they needed in order to 'solve' the task. These questions came about due to the lack of information given on the task sheets; the groups were expected to make assumptions. The vast majority of the cohort found making assumptions to be extremely difficult since their a priori experience was one of being told what to learn, when to learn and how to learn. They were able to demonstrate good procedural knowledge and skills provided they knew the equations they had to work with. Being asked to make assumptions and work from them did not provide them with the level of 'security' when being given the equations by an authority figure such as a teacher. Many of the groups found identifying appropriate mathematical constructs difficult and when asked about the interpretation of the constructs they decided upon, their lack of conceptual knowledge was apparent. One example of this was when one group were asked the meaning of $8e^{-0.1t}\ \mu g/h$ within the context of a drug release problem and were unable to identify the role of the decaying exponential function. On a more fundamental and practical note some groups were unable to realise if a proposed resolution was sensible. For example, in the task given in Appendix 1, one group couldn't work out why their water tank was being emptied in a very short time. Their resolution to the problem gave the cross sectional area of the outlet pipe as $1m^2$ and their tank had a volume of $1m^3$. It was apparent they could not visualise the dimensions even though their calculations were correct. Another group asked what an appropriate flow rate would be. They

had searched for some data on this but were unable to find any. When it was suggested, after a protracted discussion, they could measure this simply by recording how long it took to fill a one litre jug of water from their domestic water supply, they were dumbfounded. It had not occurred to them to use such simple means of investigating a problem.

Evaluation by an Independent Colleague

In order to gain some understanding as to how the students were experiencing the new approach to learning maths, an independent evaluation was conducted by speaking with some of the groups during the timetabled sessions. In all, 14 groups were talked with covering 52 students.

The nature of the discussion with each group was semi-structured and focused on three key questions:

- How were they finding their experience of studying maths this way?
- What were the best features?
- What were the challenges?

Each discussion took around 10-15 minutes, depending on the number of group members present. The discussions were kept focused so as not to disturb the session any more than necessary.

Overall the students found the approach to be a positive experience. They acknowledged that it was encouraging them to take responsibility for their learning and that initially the uncertainty was daunting. Once they accepted this uncertainty, realised that there was not one right answer and had identified some mathematical ideas to work with in solving the problem, their confidence and engagement increased. Words such as 'challenging', 'independent', 'interesting' and 'practical' were commonly used, as were 'tough', 'frustrating', 'tricky' and 'disconcerting'. One group member studying electronic engineering considered the approach 'refreshing' as he and his group appreciated the time to experiment and set targets for themselves as would perhaps be necessary in a real-world application.

Along with the features identified earlier, the opportunity to take a problem from brief to solution, doing research and working with others was identified by many as a positive about the approach. On the reverse, the dysfunctional nature of some groups and the lack of engagement of certain members was seen as a problem. This suggests that some briefing in how groups should work and how they can be better monitored should be considered. Peer review was incorporated, but still some students did not engage.

The more able individuals and better performing groups clearly relished this new approach. The ways in which the groups went about the work varied with some groups sharing tasks and others having all members do the same task and then pooling the ideas for consideration. Some groups actually had each group member present their ideas to the group prior to the decision making discussion.

The poorer performing groups clearly struggled with the lack of definition and vague nature of the path to a solution. This was often not helped by group members not fully engaging leading to certain individuals feeling as though they were carrying the entire group. These groups also seemed to struggle with time management and suggested that the move to this approach was bigger step than they would have liked.

Improvements suggested by the students were to offer some more generic guidelines about the problem solving approach being adopted and to have more interim feedback opportunities on the work being done. Both of these would be helpful in building confidence, without impacting the deliberately uncertain and ill-defined nature of the tasks.

Summary

Although initially the majority of the students found this approach to learning mathematics very challenging and could not see the benefit, by the end of the teaching period their attitudes had changed. Most of the students indicated they enjoyed the responsibility of having to resolve a problem with minimal guidance. They liked the notion of being trusted to come up with a viable mathematical model and, from a mathematics learning perspective, many students learned how to interpret the equations they used. The main issues they found challenging were having to work in groups, especially dealing with conflicts and group members not completing designated tasks on time, making assumptions, and interpreting and making sense of the mathematics they used to resolve the problems.

In light of this research and previous work[3] the following conceptual model (Figure 2) was developed to depict how the learning journey of an engineering student could proceed.

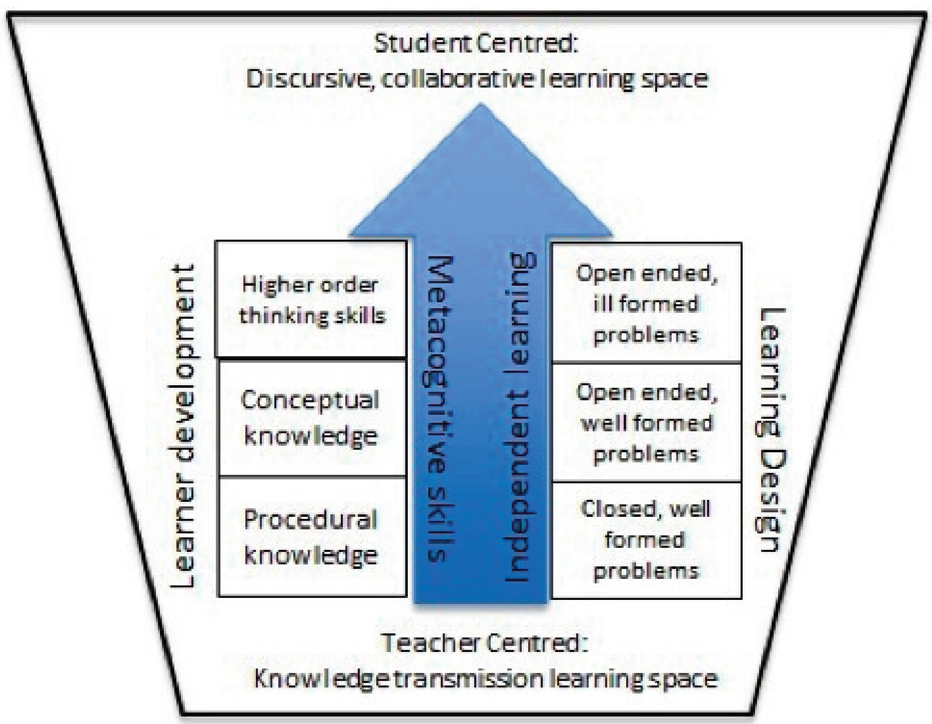

Figure 2, Conceptual Model of an Effective PBL Environment (Peters, 2016)

Although the above discussion has been brief, it shows that many students who choose to study engineering at university, are ill prepared. It seems the UK education system is failing to foster the 'habits of mind' necessary for the development of future engineers and scientists. One telling statement from the report commissioned by the Royal Academy of Engineering[2] (p11) concerning the education of young people infers a depressing picture of the current system prevalent in the UK:

> *Far from educating children out of the very ways of thinking and acting which we want to see much later in their lives, we could decide to ensure that such EHoM are cultivated throughout school life, wherever they may occur. Designing, making and tinkering are what children do instinctively. They are also desired outcomes for trained engineers!*

This situation means that UK universities have to carefully consider how the learning of their students is managed. This is especially true in the first year where the majority of students start to develop their mind-set regarding their approach to becoming professional engineers. Once a firm foundation of 'habits of mind' has been laid, subsequent years can build upon this to such an extent that, by the time the student graduates, higher order thinking skills are instinctive.

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Appendix 1
Applying Mathematics - Supplying Water

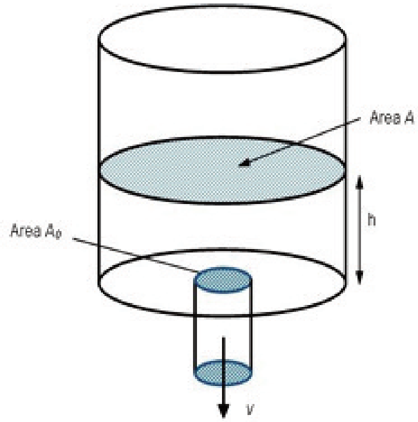
Challenge level - 2 Maximum marks 80

Scenario

You have decided that you have had enough of living the 'rat race' culture prevalent in the UK. You have done some investigative work and decided to move to Northern Belize, buy some land and build a new life where you are in control. One of the first tasks, after building a shelter, is to build a water storage tank so you can have fresh water all year round. In your investigations you found out that Northern Belize has a rainy season between June and November where, on average, 1524mm of rain falls.

You decide upon a cubical tank with a water outlet at the bottom. Your initial 'guess' at the dimensions for your tank were: sides 3m with a drain hole of diameter 0.1m.

Unfortunately you can only find information on a cylindrical tank as shown in the diagram.



Initial Tasks

(a) Find a differential equation relating the height, h of the water at a time t.

(b) Solve this equation for the initial conditions $t = 0$, $h = 2$.

(c) How long, in minutes, does it take to empty the tank which is $2m$ full?

(d) Decide how much fresh water you require per year and design an appropriate size tank.

Main Task

Using Matlab develop a mathematical model to investigate different sizes of tanks and different flow rates so you have access to water all year round.

Pursuing excellence

Mrs Laura Leyland, Dr Jens Lahr, Mr Simon Handley, *School of Engineering and the Built Environment, Birmingham City University* (with thanks to Prof Michael Ward and the Engineering team)

"Transforming the Curriculum" at Birmingham City University is a transitional change project promoting innovative approaches to teaching and learning across all areas of the university as every course is redesigned for delivery in September 2017. Particular themes of the new curriculum are a value-added curriculum with a transformative practice experience. The vehicle of this project has enabled large scale change of our engineering provision, which would not have been possible through the normal routes which promote incremental change.

The challenges facing our engineering education are representative of the sector; very few women on our courses, a full curriculum with a lack of space to develop professional skills and a fragmented timetable with content taught in standalone modules. Our metrics are currently below our targets and we are in a position where the status quo is not an acceptable option, radical change is required.

The number of women on our courses falls way below the sector mean, with 0.38% female enrolments in 2014 on the BEng Mechanical and BEng Automotive courses.

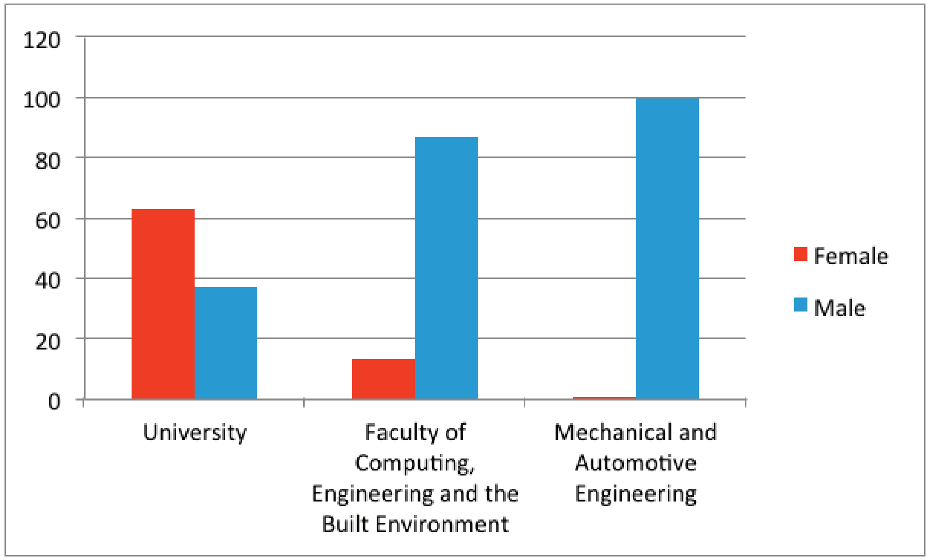


Figure 1 Foundation and first year entry 2014 by gender

Historically, the engineering courses at Birmingham City University have had an "automotive branding", with a large proportion of our graduates heading to Jaguar Land Rover and the associated supply chains.

Figure 2 Typical imagery used in marketing BEng programmes at BCU

This can be seen from the imagery used in marketing materials, see figure 2, websites, case-studies and in the materials used to discuss with prospective and current students.

We recognise that we have not been challenging the societal skewed view of what makes an engineer, and we are now striving to promote a different route. Addressing the "Engineering habits of mind"[1] and ensuring that our new courses will develop the emotional capabilities that make the difference in career success, for example; interpersonal skills, teamwork, leadership and emotional intelligence, Goldberg[2], aligning with the curriculum transformation objectives and the key skills and attributes that employers are asking for.[3]

In addition the addressing of the learning outcomes as set by the accrediting institutions is a key factor that was addressed to support the professional development route of the students towards chartered status.

Macdonald[4] introduces the difference in language to which males and females associate themselves. Where females associate with collaboration, males with competition. Females with adjectives and males with verbs.

The below is taken from the BCU webpage for mechanical engineering:

> *You'll work on the latest industry-standard computer-aided engineering (CAE) tools and outstanding facilities for engine testing, rapid prototyping, engine emissions testing, and thermodynamics, alongside your academic studies, giving you a fully rounded experience.*

Moving forward we will approach our communications with a person specification (adjectives) as well as a job specification (verbs).

> *You'll work in* teams *with engineers from across the faculty, with the latest industry-standard computer-aided engineering (CAE) tools and outstanding facilities for engine testing, rapid prototyping, engine emissions testing, and thermodynamics to find and build* sustainable, affordable *solutions to* global *problems such as energy and water supply giving you a fully rounded experience.*

The opportunity to effect wide scale, and lasting, change was led by the vision for the engineering programmes to widen inclusivity, to be practice-led and knowledge-applied, providing opportunities for students to gain deeper subject knowledge whilst developing professional skills and experience relevant to the work place, to discover the Joy of Engineering.[2]

This will be achieved through incorporating CDIO (Create Design Implement Operate) teaching framework, with students working on design-implement projects at every stage of the course, from level 3, foundation year. This project has enabled us to develop a common

engineering first year, level 4, across six engineering courses: Mechanical, Automotive, Manufacturing, Bio-Medical, Electronics and Civil. This will also ensure that students have the practical experience of applying engineering science to real world problems, working in multidisciplinary teams to develop their interpersonal skills, a key feature of modern engineering practice. Supporting the project working, students will additionally have very small group tutorials to develop a sense of belonging, opportunities to receive early feedback, scaffolding both the development of writing skills and critical thinking.

The design-implement projects both support and are supported by the theoretical modules. A key goal of the CDIO approach is to educate students who are able to master a deeper working knowledge of technical fundamentals and practice[5]; engineers need good fundamental knowledge to be able to find appropriate solutions.

Although not actively encouraging students to fail, the implementation allows for a more risk taking approach in the project work, allowing students to investigate the limits of their learning and knowledge implementation and dealing with potential setbacks, an experience well worth making without major implications on real life and widening their mind for active assessment of pitfalls.

It also encourages a transition of mind from the "A"-level based learning for exams to fully engaged search for solutions with help approach.

Cross-curricula working is continued with a second year module, where students will have developed course specific skills and knowledge to bring back to team working as they develop competencies in "leading engineering endeavours".

The new programmes will be addressing a range of industries and issues, not just cars and engines. Students will be working creatively, and collaboratively to solve problems such as simple roller-coaster design or addressing key challenges from the UN Sustainable Development Goals, for example, drinking water for a community in Lobitos, Peru with the Engineers Without Borders Engineering for People Challenge.

Besides the enhancement and improvement of the students learning experience it was also recognised that the TtC was an important factor in the development of staffs teaching performance and approach. The change from formal tutorials to bespoke learning group teaching required a change in mind set, a challenge not to be underestimated. As with changing the perception of engineering in the wider society it is also the change and the win over of all staff to be actively embracing the new teaching style, although complexity involved can be daunting at times.

Implementation challenges – the roadmap to joining the CDIO collaboration and the new courses

The initial benchmark of our engineering provision against the CDIO standards is completed[5].

Progress towards the new curriculum includes two pilot projects currently being undertaken by our first year engineering students.

Teams of undergraduate students are employed as Student Academic Partners (SAP) to support and guide the writing and development of practical activities.

CDIO implementation to the framework requires ongoing "Enhancement of Faculty Competence" CDIO Standard 12. The CDIO community has been and continues to be incredibly supportive of our implementation. Two members of the engineering team have attended CDIO conferences, and many staff have visited Aston University, our most local CDIO partner. The UK and Ireland group are supporting us with faculty training workshops.

The new programmes have been designed and approved for delivery in September 2017. The programme teams recognise that students continue to place professional accreditation at the top of their wish list when identifying what they want from an engineering course. All of the engineering programs will provide the necessary Engineering Council accreditation for progression to Chartered Engineer status, CEng, through accreditation with the appropriate professional institution. This will only be supported and strengthened by joining the CDIO collaboration.

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Responding to the changing HE environment:

Developing a sustainable engineering curriculum for part-time distance learning students

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Abstract

This paper outlines the changes made to the engineering curriculum at The Open University in response to funding changes implemented in 2012 which enabled part-time, distance learners in England to access student loans. The paper also describes changes to overall qualification design including the way in which mathematics is taught to engineering students, moving away from 'service teaching' towards incorporating mathematics teaching into the core engineering modules. Mathematics is now taught in the context of engineering with less emphasis on derivations and mathematical proofs and with greater emphasis on understanding basic concepts and being able to create useful models. Personal and professional development planning has also been embedded into engineering teaching for improved context and relevance.

1. Introduction

The Open University (OU), based in Milton Keynes with six national and regional centres across England, Scotland, Wales and Northern Ireland, is one of the largest universities in the UK with over 170,000 registered students. This total includes approximately 4500 students currently studying towards an undergraduate Bachelor of Engineering (BEng (Hons)), Bachelor of Engineering Top-up (BEng (Hons)), Master of Engineering (MEng), or Engineering Foundation Degree (Eng FD).

The OU has an open access policy and, with very few exceptions, there are no formal academic entry requirements. Some students on the engineering programme join with no previous educational qualifications (PEQs), though often with extensive practical vocational experience, whilst others may bring transferred credit from HNC or HND qualifications. The majority of our engineering students are in full-time engineering-related employment.

As a result of higher education funding changes for England in 2012, the OU changed its student registrations from module-based to qualification-based to enable access to loans for part-time study. This change resulted in more prescriptive and structured routes through the engineering degrees as well as identification of students registered for particular qualifications. This enabled the performance of students on individual modules making up the qualifications to be interrogated more easily at a qualification level and problems identified. The changes were reported by Organ and Morris[1] in 2012.

We identified that engineering students were performing poorly on two, 30 credit, compulsory mathematics modules and consequently failing to complete their first year (equivalent full-time) of study successfully. Anecdotal evidence and feedback from students suggested that engineering students would benefit from greater connections between mathematics principles and relevant engineering topics and techniques.

Personal development planning (PDP) and professional skills development towards employability have featured in the OU engineering qualifications for a number of years. However, distinct PDP modules have not proved as popular with students as core engineering modules. The importance of these skills to a student studying towards an engineering qualification were not as widely recognised by students as intended, predominantly due to these modules being studied in isolation.

Following an evidence-based approach we proposed a restructuring of the engineering qualifications to incorporate mathematics teaching in an engineering context alongside key skills and PDP. The new structures incorporate revised study patterns allowing students to pace their studies more effectively alongside their work and family commitments. Teaching is delivered primarily as print and online media distance learning with some face-to-face tutorials and laboratory based residential schools.

Mathematics skills, personal and professional development planning, practical laboratory based residential schools, and wider skills are all integrated into broader modules that provide context and relevance to students while they are studying engineering topics. We have also taken an integrated approach to assessment, developing an assessment strategy for each stage of the qualification rather than on a module-by-module basis.

2. Curriculum changes

i. Mathematics in an Engineering context

The wide range of student abilities in mathematics skills and preparedness on entry to engineering degrees has been recognised as problematic for a long time.[2] The problem is exacerbated at The Open University as students come from a wide range of educational backgrounds and may not have studied mathematics formally for many years. Many students also exhibit low confidence in dealing with mathematics. Approaches to help students on entry to conventional HEIs[3], such as additional lectures or drop-in support sessions, are impractical in a distance-learning setting. We know that the majority of our engineering students are in full-time employment and frequently combine study with work and family commitments and have finite time for study. Strategies that give students additional workload to strengthen their mathematical skills are unlikely to succeed in the context of the OU.

From October 2012 to February 2016 our engineering students were required to study 2 x 30 credits of mathematics at level 4 from a choice of 3 x 30 credit modules. The two modules included a compulsory 30 credit module in Essential Mathematics. The second mathematics module choice would either further support open entry students requiring more introductory practice in mathematics or alternatively provide a more challenging mathematics module for those more mathematically confident students intending to study further engineering mathematics at a higher level. The compulsory Essential Mathematics module was designed primarily to satisfy the requirements of the mathematics teaching programme and students on mathematics qualifications. The module was available to study either from October to June or from February to September each year. The proportion of BEng (Hons) students gaining credit on Essential Mathematics in the period from October 2012 to February 2016 varied from 34 to 51 percent.

Although there was an upward trend in the percentage of BEng (Hons) students gaining credit

over the period it was, nevertheless, at an unacceptably low level and having a detrimental impact on progression from level 4, as students were required to either re-sit the end of module examination or retake the module at the next opportunity.

From October 2016 students no longer study mathematics modules in isolation. We have integrated mathematics teaching into the core engineering modules, ensuring that it is taught in context.

Much of the base content has been adapted from the existing mathematics modules. The emphasis has been on understanding basic concepts, creating useful models and recognising reasonable solutions to engineering problems. We also encourage students to experiment and to use dimensional analysis to aid their understanding and to check their results. We have placed less emphasis on deriving or proving mathematical relationships or using specific methods at this early stage of the qualifications. We hope that our approach will discourage students from learning mathematics by rote and consequently being unable to apply it to unfamiliar situations.

ii. Personal development planning (PDP) and skills development

We have incorporated PDP into our engineering qualifications for many years to ensure our graduates are well prepared and to enhance their employability. Our qualifications align with the requirements of the UK Standard for Professional Engineering Competence (UK-SPEC).[4] Prior to 2012, students were required to study 2 x 15 credit specialist PDP modules at level 4 and level 6. Student loan funding changes in England necessitated combining learning content into larger credit modules. This provided the opportunity for us to integrate PDP into other engineering modules. We have done this by integrating PDP with technical content, engineering professions case studies and compulsory practical engineering residential schools to produce 2 x 30 credit modules – one at level 4 and one at level 5.

It cannot be assumed that on entry to The Open University students automatically have the skills required for successful study at degree level as approximately one-third enter the university with no 'A' level (or equivalent) qualifications. Even those with conventional university entry qualifications frequently lack the skills required for distance-learning or have not studied for several years.

As with mathematics, we have taken the approach of integrating PDP and study skills into core engineering modules, enabling key skills such as communication, presentation skills and report writing to be studied alongside relevant engineering concepts. Students maintain a log of their learning activities which forms the basis of a portfolio of evidence which can be used if they subsequently apply for chartered status with a professional engineering institution after graduation.

iii. Study patterns

Prior to October 2012 engineering students could study up to 120 credits in an academic year, although the majority chose to limit their study to 60 credits a year. However, the times at which different modules were available meant that approximately half of new entrants to the engineering programme were studying 2 x 30 credits concurrently (from October to June) resulting in high intensity study, and then having a break until the following October. This study pattern meant that students often had conflicting assessment cut-off dates and were frequently struggling to get their assessments submitted on time.

We have amended study patterns so that students study the first 2 x 30 credit modules of their engineering qualification in succession over a 12 month period, with the first module, (Engineering:

origins, methods, context) being studied from October to March and the second (Engineering: frameworks, analysis, production) studied from April to September. Our aim is to ensure that students do not have conflicting assessment dates, are able to concentrate on one module at a time at this early stage of study, and are able to utilise knowledge and skills acquired in the first module to successfully study the second module. Sequenced skills development plays an important role alongside knowledge attainment as students progress through the modules.

A schematic of the modules studied at level 4 for the BEng (Hons) and MEng is given in Figure 1.

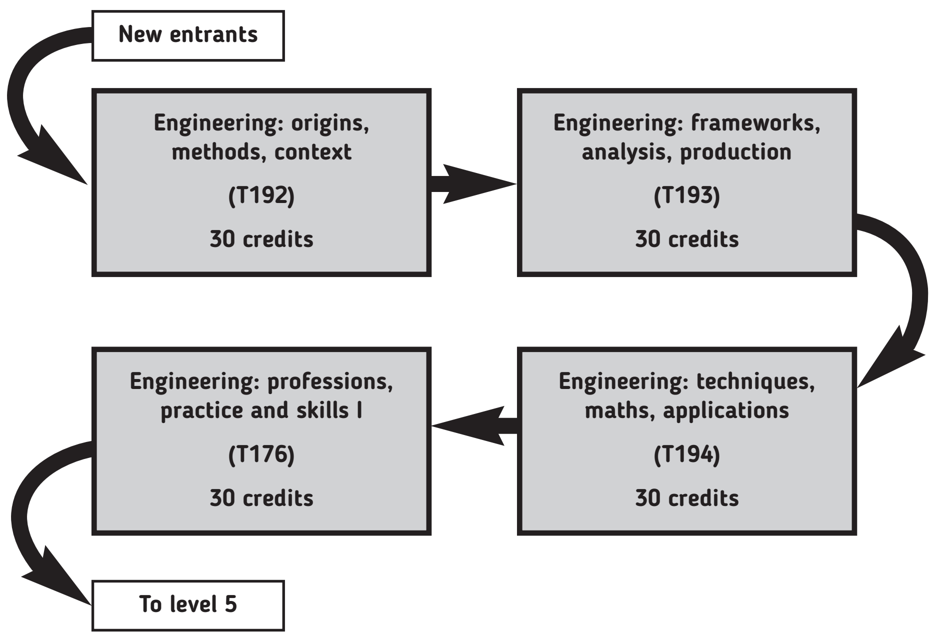

Figure 1: Schematic of study order for new entrants to OU engineering qualifications from October 2016

3. Assessment

We have taken a qualification-based approach to assessment, ensuring that assessment tasks build in difficulty as students progress through each module and build in type as they progress through the qualification stage. Students are required to complete formative activities designed to feed into summative assessment at regular intervals and if they complete these activities at the appropriate time assignments should be straight-forward and not the last minute rush often experienced by part-time learners. Pacing of assessment activities in this way also benefits reflective skills development as adequate time remains close to an assessment deadline for students to review their work, complete self-assessment reflective activity, and finalise their assessment submission. Student self-assessment of learning outcomes attainment is also built in to assessments, ensuring good student engagement.

Students are continuously assessed through tutor-marked assignments (TMAs) and interactive computer-marked assignments (iCMAs) combined with end-of-module assignments and examinations where appropriate.

Practice quizzes are incorporated into most weeks' study for the duration of the first three modules and the time taken to do them is accounted for in the overall study time. These quizzes enable students to have multiple attempts at particular mathematical problems, with feedback given for incorrect answers.

More formal mathematical assessment at level 4 takes the form of iCMAs developed at the OU and outlined by Jordan.[5] Students are allowed 3 attempts at each question, with feedback for incorrect attempts suggesting where the student has made mistakes and referring them to appropriate module material as necessary.

iCMAs and practise quizzes are combined with tutor-marked assignments to ensure that all learning outcomes are assessed appropriately.

4. Initial results

At the time of writing, the first cohort of students that entered the University in October 2016 has completed the first 30 credit module, *Engineering: origins, methods, context*. Early indications are that 754 of the 1017 new entrants (74%) have completed the first module, and almost all of those are progressing to study the second module, *Engineering: frameworks, analysis, production*, starting in April 2017. Retention rates of this order are very encouraging given that this is the first entry module of an open-access qualification where students are often encountering distance learning for the first time. This retention rate is significantly higher than that achieved by the previous entry module prior to October 2016, which varied from 65-68%. We will not be able to make meaningful comparisons with previous cohorts until all study at level 4 has been completed, but we are confident that greater numbers of students will progress successfully to level 5 and beyond.

5. Future plans

The ethos and methodology applied to level 4 of the engineering qualifications will be continued as higher levels of the curriculum are redeveloped. Based on evidence to date, and our experience so far through the redesign of the engineering curriculum, we will continue to work towards qualifications that are more integrated in nature. Engineering context is key to a part-time distance learner, particularly when they are already employed in a sector relating to their chosen academic subject. However, we have taken care when choosing examples, case studies and images not to make assumptions about students' prior experience and to make the teaching material relevant to a diverse student group. The integration of mathematics teaching with core engineering content is proving more popular with students and their tutors, particularly at the early stages of the qualifications. We will also continue the integration of personal and professional development planning with context driven technical engineering content towards enhancing student academic success and employability skills.

6. Conclusions

Although it is too early to make any firm conclusions about the success of the reconfiguration of the undergraduate engineering curriculum at The Open University we are encouraged by early indicators and the increased student retention rate on the first module of the revised qualifications.

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The NUSTEM approach:

Tackling the engineering and gender challenge together from early years to sixth form and beyond

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Abstract

Despite significant investment in initiatives to increase participation and diversity in physical and computer sciences, technology and engineering, there has not been a corresponding increase in the number of young people choosing these subjects, and a strong gender imbalance remains. NUSTEM, a collaborative widening participation and outreach initiative at Northumbria University, believes a radical rethink is necessary to solve this engineering challenge. NUSTEM is investing in the next generation by working extensively with young people and their key influencers: parents, carers and teachers, from primary school to sixth form and beyond. Building on their own original research and experience combined with previous research and recommendation from others, NUSTEM has developed an innovative model of practice and theory of change. This paper identifies the evidence that has informed the development of the approach and outlines three key requirements for increasing the uptake of physical and computer sciences, technology and engineering by young people from under-represented groups.

1. Introduction

NUSTEM is a collaborative Science, Technology, Engineering and Mathematics (STEM) initiative based at Northumbria University, Newcastle, working in partnership with industry, science and education bodies and schools to increase diversity in the physical and computer sciences, engineering and technology sectors in the North East. NUSTEM works with young people from early years to sixth-form across five regional local authorities in the North East of England: Newcastle, North Tyneside, Gateshead, Durham and Northumberland.

A literature review of evidence in what works with STEM interventions, particularly for females and other under-represented groups, alongside original research, identified three important principles that NUSTEM have implemented in their theory of change. This paper reviews each of these principles in turn, and presents the supporting evidence behind their adoption. The three principles are:

- Engagement and activities should start early in a child's education and be sustained throughout.
- Engagement with a young person's key influencers is also vital: parents, carers, schools, teachers and the wider community.
- Engagement should highlight the utility and ubiquity of STEM and STEM careers and seek to raise awareness of unconscious biases and gender stereotyping.

2. Early and sustained engagement

NUSTEM is guided by the principle that outreach activities that enthuse and inform young people from early years onwards, will encourage more young people to consider careers in engineering and other STEM areas.

Evidence shows that to generate significant impacts on participation at secondary school, engagements need to start in primary school[1 2]. The decline in young people's attitudes to science from age 11 is well-documented and a number of research studies show that children's attitudes towards school science decline even in primary schools[3 4]. Hadden and Johnstone's study reports no improvement in attitude towards science from the age of 9[5]; an indication that children are becoming disengaged with science towards the end of primary school. Despite the decline in upper primary, overall children's attitudes to science within primary schools remains generally positive[6]. Primary school teachers are therefore in a good position to sustain interest in science through to upper primary ages. To sustain primary children's positive attitudes to science, the Wellcome Trust recommends making primary science more relevant to children's everyday lives, and placing a greater focus on children's thinking, questioning and investigative skills[6].

Children also begin to form their occupational aspirations within primary school. At the age of 6 – 8 years, naïve early understandings turn them towards some possible futures and away from others.[7] Through ages 9-13 children further limit the number of possible occupations; for being for a different gender, the wrong level, or being beyond their capabilities.[7] Children rarely reintroduce occupations once they have been dismissed, and therefore primary schools can play a key role in supporting children to keep their options open across a range of careers. A number of studies have recommended that efforts to broaden young people's aspirations, particularly around STEM, should begin in primary school, finding that secondary school interventions and activities are 'too little, too late'.[1 2]

As well as early intervention, NUSTEM believes that regular, sustained engagements are crucial for success. The UK STEM Education Landscape review finds that, despite there being over 600 organisations involved in the STEM education landscape and significant investment into activities and interventions over four decades, *"there is little robust evidence of the long-term impact of informal science learning activities in the UK"*.[8] Many STEM engagements are one-off activities, rather than a series of activities, or sustained engagement over a long period of time. A more sustained programme of activity integrating careers awareness into the STEM curriculum is more likely to be effective.[9 10 11]

3. Build understanding and confidence of key influencers

Teacher and parental lack of confidence in their STEM ability, can exert significant influence on children's aspirations and decision making. NUSTEM believes that engagement with children's key influencers to improve confidence is necessary to improve participation in STEM.

Since science became a core subject of the primary curriculum in 1989, there have been frequent concerns raised regarding primary school teachers' ability to teach science effectively.[3 12 13] Teachers must have a good understanding of science concepts and the science curriculum if they are to impart this knowledge to children effectively. A lack of knowledge, *"leads teachers to display a closed pedagogy where the presentation of unrelated facts takes precedence over conceptual understanding"*[13] (p33). Palmer's research discovered that teachers who lack confidence in their own

science abilities, are more likely to be critical of students and give up on students encountering difficulties more readily.[14] Additionally Jarvis *et al* found that without a firm understanding of science concepts beyond the science curriculum, teachers develop misconceptions that can interfere with children's understanding.[4] Only 3%- 5% of the UK's primary school teachers hold a science or mathematics degree, which means that many schools have no one with an undergraduate qualification in mathematics or science.[15]

Evidence shows that high-quality training, guidance and resources can improve primary school teachers understanding and confidence.[4 6] Palmer found that primary school teacher confidence could be improved through observation of good practice first hand, and then the opportunity to model good practice in the classroom.[14] Teachers who undertook professional development in science felt more confident to assess and set up practical work, explain scientific ideas and ensure all children are engaged in science learning.[6] NUSTEM have been supporting primary school teachers to develop their career, subject and pedagogical knowledge, and empower them to lead science within their schools through CPD in science teaching and scientific principles at a regular Primary Science Coordinators forum.

At secondary school level education, the concern lies not with the lack of understanding of science content, rather that many science teachers have a limited understanding of careers in science, or the range of careers that science qualifications give access to.[2 16] Without knowledge of the role of science in the wider world, teachers and careers advisors are unable to adequately prepare young people for future study or careers in science.

It is less certain, however, how secondary careers education can be improved. Osbourne and Dillion recommend that schools improve resources available to inform students of careers in science, particularly emphasising the role of science as a cultural and humanitarian activity so as to appeal to girls, as well as emphasising that science qualifications can act as a door opener to a wide range of potential careers.[17] The OFSTED report 'Going in the Right Direction' highlights the good practice of where classroom teachers embed careers information into the general science curriculum, using first-hand, industry related knowledge to inspire students about careers education.[18] In secondary schools, NUSTEM is supporting science teachers to embed careers information into science teaching, providing access to diverse examples of related careers and linking schools with local STEM industries and employers.

Lack of confidence in science is not just a problem among teachers. A recent IET survey found that many parents lack confidence in their science ability, with 83% of UK parents unable to answer basic school-level 'science' questions, and 61% of parents fearful of being asked difficult questions by their child.[19] Similarly, parents of older children are often unaware of the possible education routes and career paths that studying STEM can lead to.[1]

Parental engagement is one route to improving the science confidence of parents. The association between parental involvement and educational achievement is now well established. However, further research is needed to establish which types of parental engagements are likely to be most effective.[20] Gutman and Akerman maintain that since aspirations are formed young, early engagement with parents, particularly those in disadvantaged areas, is key to developing parents' early aspirations for their children and children's early aspirations and attitudes.[7] A number of studies have examined the role of parental engagement on children's literacy and numeracy outcomes, but few studies have examined how parental engagement can improve science outcomes, or the confidence of parents.[21]

NUSTEM supports parents to more involved in their child's science education, and more confident in talking to their children about science. This involvement occurs through workshops, take-home activities, online, as well as five-week family learning courses ‘Science for Families’ and ‘Engineering for Families’. These are successful in encouraging families to talk more about STEM at home. Additionally NUSTEM provides CPD in science parental engagement to schools.

4. Drive for wider social change

NUSTEM recognises that STEM interventions can only go so far in supporting children and young people to choose a future in STEM. Young people’s aspirations and decision-making processes are shaped by their perception of themselves and their abilities, as well as their environment and social sphere, not just their interest and enjoyment of subjects and their experiences in the classroom.[22] Females’ educational and occupational choices may be further restricted by gender role stereotypes and gendered attitudes.

Assumptions about the differences between females and males permeate modern life, culture and education.[23] Historically the differences between the genders were thought to be determined by biological factors, however the dominant discourse today is that gender is socially and culturally constructed through our interactions in society. Children’s understanding of what it means to be male or female, are therefore determined by their experiences and interactions in their daily lives.[24] Research shows that children begin to follow gender stereotypes from before the age of five, and are often enthusiastic enforcers of gender conformity.[25]

Stereotyping is universal, unconscious, and an unavoidable function of our brains, which enables us to think and act with speed and efficiency.[26] However, it can also have negative, unintended consequences. Research has shown that teachers commonly under-rate the academic ability of low-income pupils, non-white pupils, pupils with English as an Additional Language. Teachers also commonly under-rate the performance of male pupils in English and female pupils in Mathematics.[26] Sadker & Zittleman found that on average, teachers give males more time than females to answer questions in class, with white males receiving the most attention from teachers.[27]

While impact of stereotyping on an individual particular outcome may be small, the effect of multiple stereotypes over time in different contexts, results in substantially different outcomes for children, of otherwise similar backgrounds or abilities.[28] Boys are twice as likely to study Mathematics, three times as likely to study Further Mathematics and more than four times as likely to take A-levels in Physics, while females are twice as likely to study English compared to boys.[29] Bian et al, found that from as early as 6 years old, females are less likely than males to believe that people of their gender are ‘really, really smart’, and that a significantly higher proportion of females begin to avoid activities said to be for ‘really, really smart’ children, compared to males.[30]

Unless unconscious biases are addressed, they may continue to play a part in creating and perpetuating existing inequalities in society. It is important that anyone working in STEM education and engagement is reflexively aware of the ways that unconscious biases and gendered ideas influence practice and behaviour, and serve to constrain the learning experiences of children and young people.[26 31]

Unconscious bias and gender norming are societal issues that cannot be solved by the education system alone. However, teachers and educators in informal STEM learning remain in a strong position to promote equality through their practices. Earp highlights how teachers can with time and reflexive effort, can ‘train’ themselves to tame the stereotyping mechanism, by presuming motivation and ability in all students, drawing on alternative stereotypes of pupils, and being consciously balanced and constructive in interactions with and feedback to pupils.[31] The IOP’s Closing Doors report found that the majority of schools fail to encourage subject choices in a gender neutral way, and that attempts to increase the number of females taking A-Level Physics would require changes to the whole-school culture not just the physics classroom.[32] The IOP’s ‘Improving Gender Balance’ reports success with a whole school campaign on gender stereotyping. The programme influenced teachers to change the style and content of their teaching, to self-reflect more in regard to gender neutrality, to use more gender-neutral language within the classroom, and more diversity within careers examples.[33]

NUSTEM is delivering Unconscious Bias Continuing Professional Development to teachers, education practitioners, academics, employers and industry across the North East and beyond. These sessions raise awareness of gendered language and common gendered behaviours, and ask participants to consider these in their engagements with children and young people. In schools, NUSTEM delivers CPD to staff across a whole school or department rather than just to science teachers, and provides additional support to schools to review their equality and diversity strategy and approach. Additionally NUSTEM works with industry and employers to review their education programmes and develop new practice that will help reduce unconscious biases in engagement work. By teaching this topic as part of the syllabus for Northumbria University Trainee Teachers, NUSTEM are raising awareness of unconscious bias among the next generation of teachers and offering them the tools to challenge biases within their teaching practice.

5. Conclusion

Lack of diversity in physical and computer sciences, technology, and engineering continues to be an issue despite over four decades of activity aimed at increasing diversity in these fields. NUSTEM have identified a need for universities and companies, and those delivering STEM engagements to adapt their approach and their target groups for their engagements. There is a real need to work with primary school children and their key influences, as engagements with secondary pupils are often too late to have the needed impact. Curriculum-related and careers inspired activities highlight the relevance of and possibilities within STEM, while regular and sustained engagements ensure there is support throughout a child’s formative years. Wider societal issues are beginning to be addressed through an awareness of unconscious bias and the development of structures and processes to minimise the effect of bias, but there still much work that can be done in this area.

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Women in engineering at the Open University – motivations and aspirations

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Abstract

This paper provides an introduction and rationale for research which is to be undertaken at the Open University on the motivation and career aspirations of mature, female engineering undergraduate students. The work will commence from April 2017 for a period of 18 months.

Introduction

The Open University (OU), based in Milton Keynes with six national and regional centres across England, Scotland, Wales and Northern Ireland, is one of the largest universities in the UK with over 170,000 registered students. This total includes approximately 4500 students currently studying towards an undergraduate Bachelor of Engineering (BEng (Hons)), Bachelor of Engineering Top-up (BEng (Hons)), Master of Engineering (MEng), or Engineering Foundation Degree (Eng FD).

The OU has an open access policy and, with very few exceptions, there are no formal academic entry requirements. Some students on the engineering programme join with no previous educational qualifications (PEQs), though often with extensive practical vocational experience, whilst others may bring transferred credit from HNC or HND qualifications. The majority of our engineering students are in full-time engineering related employment.

The number of women registering on The Open University's undergraduate engineering qualifications has remained fairly constant since the introduction of loans for part-time distance learning students in England from 2012. There has been a small growth in overall engineering student numbers since 2012. However, women only account for 10.5% of the undergraduate engineering student population, with an intake of approximately 100 female students annually. 75% of these women are aged between 25 and 39 years, with only 2% aged under 21.

There is some anecdotal evidence from conversations with women students at engineering residential schools and at a 2016 National Women in Engineering Day conference held at the OU that they choose engineering qualifications as a result of already working in an engineering environment, but that they do not necessarily have a job role which could be described as engineering at the start of their studies. We know that 76% of these students are in full-time employment with another 10% in part-time work.

A recent Institution of Engineering and Technology (IET) survey showed that only 9% of the engineering workforce is female[1] and EngineeringUK state in their *State of Engineering* report[2] that only 4.9% of registered engineers and technicians are female. There have been many initiatives over the past 30 years to increase the number of girls entering higher education institutions (HEIs) to study engineering, but no substantial work exists, as far as we are aware, on understanding the motivations of mature women to study engineering.

Intended research and methodology

We have been awarded a small research grant to investigate the motivations of women studying engineering qualifications at the OU as a first step in helping to increase the number of women on such qualifications. We also seek to understand their career aspirations which could inform curriculum strategy.

By gaining an understanding of Open University female engineering students' motivations and experiences we can recommend strategies for increasing the registrations of women students on engineering qualifications and provide better advice and guidance at the pre-registration stage. We also aim to gain an insight into any aspects of the current curriculum offer which may be inadvertently discriminating against female students through unconscious bias or whether we have made inappropriate assumptions about their prior learning and experience. A longitudinal study of women returning to Science, Engineering and Technology (SET) after a career break identified several gendered factors as barriers to employability[3] as well as strategies for overcoming those barriers. We aim to build on this work and provide strategies to help our female students gain employment in engineering on graduation.

The research, due to start in April 2017, will consist of three phases, detailed below.

- **Phase 1 –** literature review of existing strategies and interventions from UK HEIs encouraging women into engineering.
- **Phase 2** - focus groups and interviews with current OU women engineering students. We plan to have 6 focus groups enabling students to choose a time to suit them and up to 10 individual in-depth interviews.
- **Phase 3 –** online survey (informed by focus group and in-depth interview outputs) for all actively studying women engineering students. Our aim is to understand the demographic of our female students alongside their motivation and career aspirations.

Dissemination and further work

On completion of the research the findings will be disseminated internally and externally via engineering education conferences and journals.

References

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Learning to avoid the traditional gender bias

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Abstract

Many disciplines exhibit a strong gender imbalance, with the potential to lead to a male or female bias alike. The arguments of nature vs nurture in various professions is a key point for discussion. Electronic Engineering is a field that has been and remains heavily biased towards male participation. This paper discusses the motivation for re-examining the gender bias question in the context of teaching Electronic Engineering, key considerations and ways forward.

Introduction

At Royal Holloway we are in a unique position to make a real change. Royal Holloway consists of two founding Colleges: Royal Holloway College and Bedford College. The colleges were founded in 1879 and 1849 respectively in order to grant women access to higher education, which was a radical concept at the time. In 1965 both colleges admitted their first male students, but their strong commitment to women's education remained.

Royal Holloway has opened a new Electronic Engineering department in 2016, which will admit its first cohort of undergraduate students in September 2017. The department currently consists of Prof David Howard, Dr Wenqing Liu and Dr Stefanie Kuenzel. Having a 1:2 male to female gender ratio in an Electronic Engineering department is highly unusual and part of this can be attributed to small numbers. We are in the lucky position to be able to demonstrate first hand that engineering is for women and men alike. This has been very successful judging from our experience with applications to date and considering only 15.8% of engineering and technology undergraduates in the UK are female.[1] 29.63% of our undergraduate applicants have been female. It is our aim to further raise awareness that engineering can be for anyone with the right aptitude.

Considering the strong gender bias in our field and our motivation turn a fresh page, has lead us to ponder over various factors that play into gender bias.

Importance of shifting gender bias

Gender bias is undesirable for multiple reasons including a narrowed pool of capable graduates, loss of the higher performance, variety in approaches to problem solving, fully inclusive coverage of experience and opinions, and varied skill sets of mixed teams and considerations around equality. Providing all with the opportunity to consider whether engineering could be the right career for them, is not only about equality, it is about granting them the satisfaction to work in a field that truly interests them, leading to job satisfaction and a happier life. Providing a path into engineering for the naturally gifted leads to the furthest engineering advances we can achieve, enabling the greatest future for our society.

Awareness of gender bias

In the first instance we need to understand the extreme social as well as unconscious bias that we live with every day. Such bias is far more than the choice of toys; it is subtle things such as the form of conversations we lead, how we carry out our daily chores, and unsaid expectations. Will two people talk about their work, science and politics or about fashion and the daily gossip? Who will take the minutes and organize the catering for a meeting? Who will organize the birthday card for a colleague? We live with gender bias deeply rooted into our daily routines, and most of the time it is unconscious. Upon understanding the strong pulls society norms have, we need to consider the most effective route to open doors to everyone who has an innate interest in science, technology and engineering.

While the largest part of population has an unconscious gender bias, it should not be denied that very few carry a clear conscious bias, frequently linked with outspoken opinions about what a particular gender is or is not capable of or should or should not be doing. Society has successfully overcome this attitude by and large, and it is for those that witness such attitudes to point out that views are outdated and that society has now moved on. Beating the conscious gender bias has been the first step. We should not forget the avoidance of a return to these attitudes while we work on step 2, which is beating the unconscious gender bias.

Do you see a communality between all the jobs listed in category A and all the jobs in category B?

A: Technician, Builder, Professor, Doctor, Cobbler, Carpenter, Pilot
B: Teacher, Cleaner, Nurse, Secretary, Biologist

No? Well done. Most of us have inbuilt stereotypes, which we find hard to shake. If a friend tells us they had a builder around to fix their outbuilding, we may ask if he did a good job, without thinking twice about why we used 'he' and not 'she' or to be neutral, 'they' or 's/he'.

Many times we find our expectations around gender bias confirmed by facts. If someone has an expectation that women are not suited for engineering and they walk into an engineering department, by all probability they can walk out and say: "I always knew engineering is not for women. There are mostly men in engineering departments."

However this would be a false conclusion. The lack of an equal representation in gender, does not directly reflect suitability to the career. To a large degree it reflects society stereotypes.

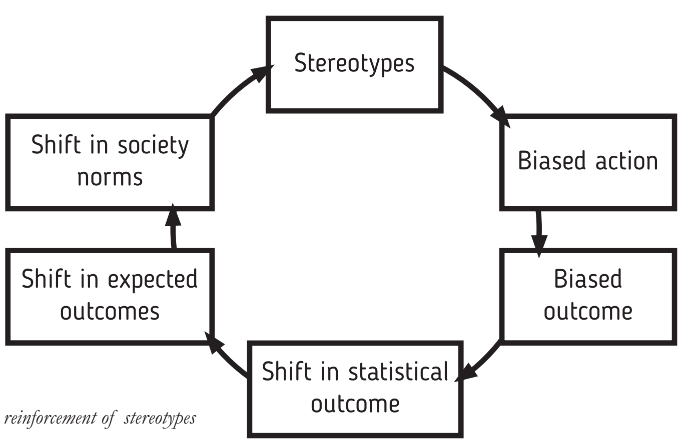

Figure 1: Cyclic reinforcement of stereotypes

Figure 1 illustrates the cyclic reinforcement of stereotypes. Stereotypes can lead to us taking biased actions, which lead to a biased outcome, the biased outcomes will lead to a shift in the statistical outcome. As the statistical outcome changes, this will change our expectation of the likely outcome. This will lead to a shift in society norms, such as talking about an engineer, using the attribute he rather than s/he. This shift in society norms allows a reinforcement of the already prevailing stereotype. Understanding this cyclic reinforcement, which leads to an increasing bias, is the first step in considering opportunities for change. It is noteworthy that this concept holds true, independent of the stereotype and can be applied beyond the gender debate.

Gender bias build into the system

Conscious and unconscious gender bias is not limited to how we interact with people around us. It is also reflected directly in the law. A very simple example is the government move from maternity leave to parental leave. One of the main factors often discussed around women in the work place is their need to look after a family. As we enter a more modern age, governments have acknowledged the capability of couples to share home making responsibilities. In theory as men and women begin to share these responsibilities more evenly, for an employer there should be little difference in hiring a men or women of about the same age. However, probably due to subconscious bias, government regulation on parental leave has failed to deliver full impact in this respect. Rather than allocating 50% of the parental leave for each parent, redistributed at the request of the mother, 100% has been allocated to the mother, which can be redistributed at her request. This subtle difference means by default a women is still more risky for a company to hire than a men. If we are serious about avoiding gender bias, we ought to review our laws, legislations and regulations and consider if they can be adapted to provide a more neutral ground.

Ways forward

Attracting girls to take STEM subjects at all cost is certainly not a meaningful responsive action. We need to ensure there is an even playing field and equal opportunities for those interested in Engineering. We need to educate the public about Engineering, what it is, why it is important and that everyone could have a fulfilling career in Engineering independent of their gender. We can use role models and positive engagement with the media. Kindergartens, schools and parents should be encouraged to allow their children to explore a variety of interests, independent of gender stereotypes, whether this is a boy playing with dolls or a girl playing with Duplo bricks. As a society we need to be willing to confront outdated views, reconsider the way our society works and whether our laws are all in the best interest of equality.

Figure 2 (overleaf) shows changes we can make to the Cyclic reinforcement of stereotypes, in order to initiate a shift from the status quo to an unbiased steady state. We can directly address stereotypes through educational campaigns. Early education is required for future generations. At the same time we need to inform the general public, which determines the early life choices for this future generation. A major impact can also be achieved, educating the key decision makers throughout our societies. The media has a very powerful impact on the stereotypes we form, this can be used in a positive way to unlearn these stereotypes as well. We can use regulatory frameworks, quotas and anonymized processes to attempt to limit the bias in our actions. We can measure the success of limiting the bias in our actions, by observing the statistical shift in the overall outcome. The processes designed to shift the bias, can be slowly ramped down, as the measured bias decreases.

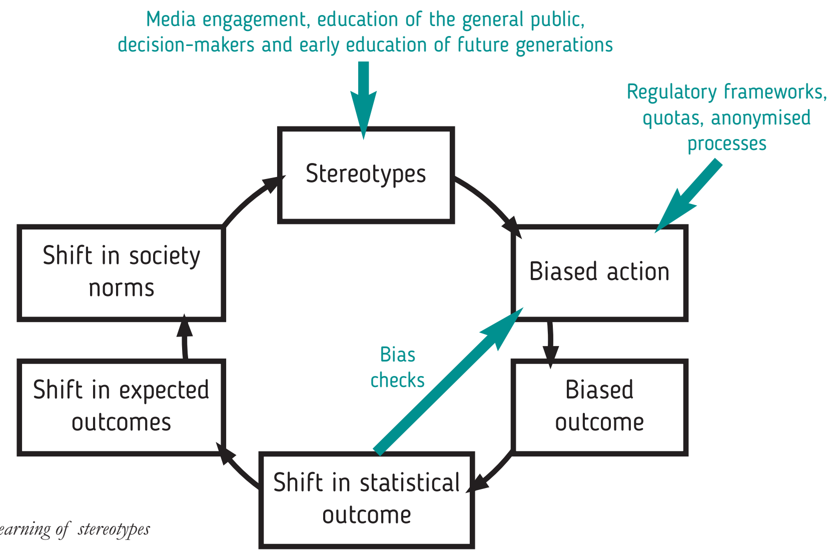

Figure 2: Unlearning of stereotypes

Conclusion

Society is continually evolving and we have made a lot of progress accepting women in the work place, into higher positions and accepting men as home makers. This has gone alongside a whole larger phase of enlightenment around other equality issues, not related to the male-female gender equality debate. Society can and should be proud of what has been achieved so far. At the same time, it is dangerous to assume that all that needed to be done has been achieved and no further progress is required. Engineering is driven by the continuous need to find a better solution, as a society we should not be complacent with something that works, if we can see a way to make it work even better.

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On 22nd May 2017, a landmark conference was held at the Institution of Engineering and Technology in London.

The task was to confront major challenges facing the world of engineering education: inadequate recruitment into universities; national skills shortages; insufficient diversity; and employers who do not recognise graduates as industry-ready.

Hosted jointly by the IET and the Engineering Professors' Council, the **New Approaches to Engineering in Higher Education Conference** laid out a bold new vision of how UK universities can better serve students, industry, the country and the whole world.