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**Proceedings Paper:**

Zandi, M., Patwardhan, S., Kotta, L. et al. (1 more author) (2018) A New Curriculum to Train Chemical Engineers to Solve 21st Century Grand Challenges. In: 5th Annual Symposium of the United Kingdom & Ireland Engineering Education Research Network: The Fifth Annual Symposium of the United Kingdom & Ireland Engineering Education Research Network, 23-24 Nov 2017, Royal Academy of Engineering, London. Aston University , Birmingham . ISBN 978 1 85449 443 6

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# **5<sup>TH</sup> Annual Symposium of the United Kingdom & Ireland Engineering Education Research Network:**

Hosted by the Royal Academy of Engineering, London.

23<sup>rd</sup> & 24<sup>th</sup> November 2017



## **“Time for Change”**

Symposium Proceedings  
March 2018.



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Published Aston University: Birmingham

ISBN: 978 1 85449 443 6

March 2018



# Executive Summary

The proceedings of the 5<sup>th</sup> symposium of the UK & IE Engineering Education Network set about challenging the status quo in all areas of engineering education. Over two days colleagues discussed and debated a number of issues ranging from engineering in schools and attracting young people into engineering, to innovative engineering pedagogies. The highly contentious question of whether 'maths' is, or is not, a vital prerequisite to studying engineering at university was debated whilst an expert panel asked the question "Are engineering educators fit for purpose?".

Needless to say the Symposium proved to be a lively event. In an attempt to provide the engineering education community with a taste of the debates the short Symposium Papers presented here represent 'the tip of the iceberg' with regards to the wide range of problems and solutions discussed and proposed. Divided into three main sections this publication shows that the Symposium did indeed achieve its objective of 'challenging the status quo'. The papers presented in the first section argue the case for change in engineering education. Whilst the second section turns to look at engineering education practice and pedagogy, with an additional section included to assure non-expert researchers are given a voice. The final section brings the document to a close with a number of papers that look at how colleagues across the UK are beginning to innovate change in the engineering classroom and beyond.

In describing each section in some detail, the following paragraphs provide a brief overview of the Symposium Findings starting off with Section 1 which begins by looking at the challenges around contemporary engineering education. Andrews and Clark highlight a frequently experienced institutional issue – the opposing pressures of accreditation and curriculum design. This is followed by Atesh et al who discuss ethical learning and development in engineering, suggesting that we have some way to go in preventing next VW incident. A paper by Kirk et al looks at research into gender and engineering, drawing attention to the importance of positive role models, Whilst the next paper by Jones suggests that that schools represent a potential weakness in the supply of suitable students to engineering, as Design and Technology teachers have confidence in delivering the arts side of the learning material selection but lack confidence in the more technical aspects of the curriculum. Andrews et al discusses the challenges and issues around school level maths education and engineering. Malik review of the impact of Artificial Intelligence and Learning Analytics approaches on student learning concluded a blended learning approach of both human educator and IT learning approach is more student learning productive.

Section 2 provides a range of papers beginning with Chance et al research highlights the impact of educators' vocab' on student learning. Shawcross and Ridgman whose research looks at skills required by engineers. The next paper by Wood and Wood discusses how a bootcamp approach was affective in equipping students with key employability skills; whilst Griffiths' paper makes the case that postgraduate programmes need to do more to also address employability skills development. This is followed by a paper by Leandro Cruz and Saunders-Smiths who highlights the importance of researching and developing a valid measurement tool to evaluate

innovation in the curriculum with relation to employability. The assessment of applied and integrated engineering skills are then discussed by Zandi et al. Mackie examines students' appreciation of human factors when engineering solutions. Deliberate practice of logbook keeping across a programme is reviewed by Junaid et al. Garrard and Nichols go on to look at curriculum redesign. A paper by Lo then introduces a heuristic framework which enables agility in learning; whilst Dziallas et al's emergent findings show how a year in industry enabled students to apply and develop technical and employability skills. Nkimi and Qi eo use explore the opportunities to harness simulation software to support engineering laboratories.

Moving on from employability and skills development, Section 3 looks at innovation in promoting change. Whilst Mitchel et al argue that in established engineering departments curriculum change is traditionally incremental, Finegold et al discuss their work in schools – highlighting the need for high quality outreach activities. Fogg-Rogers and Fowles-Sweet collaboration between engineering and teaching students to deliver a STEM learning activity has benefits for all stakeholders. A paper by Broadbent et al brings the focus back to universities demonstrating how purposive and structured pastoral and academic support can turn around failing students. This is followed by Goodhew who presents rationale for pilot study to evaluate the viability of using *wicked* projects to develop student learning in the NMiTe programme.

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# Foreword: Why is it 'Time for Change'?

Attendees at the 5<sup>th</sup> Annual Symposium may well have had the question of "*Why is it time for change?*" on their mind throughout the event in London. As a Network we feel it important that we challenge the current status quo in terms of the current educational, industrial and social context in which Engineering Education is being provided in our universities. To do this we are beginning to ask questions that, whilst possibly contentious, are certainly relevant if we are to see Engineering Education develop in a way that promotes the goals of long term success and growth. Often there are tensions between disparate groups of educators, industrialists, politicians and students; and so in exploring the need for change, one underlying feature of the Network is the desire to promote more collaboration and sharing. These Proceedings are part of that process.

As is the case with any Proceedings, this publication presents a snapshot of what is taking place within a community. When I looked back at the outputs from the previous Symposia, there was a stark difference between the Network Community some four or five years ago and the community now. I would not suggest we are mature by any means, but in terms of the work we are doing, the breadth of topics we are addressing and the questions we are asking, the Network community has certainly made huge strides over the last 5 years. The Proceedings represent a desire for change that is born out of a passion for what we do in our community. The exciting thing is that the frustrations that could manifest themselves as a collective moan are being directed into work that enriches our understanding and brings people together. The opening and closing contributions in the Proceedings illustrate the challenging conversations and innovative solutions that we are engaged in, particularly in the way they represent change; a change that is long overdue.

We do have some important systemic issues that we must overcome. The time to innovate, the recognition of our work, the support for scholarship and research and our place in the wider and fragmented Engineering Education space all need urgent attention. Our 2017 Symposium showcased what we can do, essentially with nothing. We have minimal institutional support and no significant funding. The drivers that underpin our work come out of a desire to provide a high quality student learning experience and to improve based on a solid evidential base. They are a reflection of a passion for what we do. *Just imagine what the outputs could be if were better supported!*

The Symposium Proceedings embody the Network vision: The development of an inclusive community of people researching Engineering Education (or interested in the work we're doing). The variety of contributions give a good indication of the breadth and depth of our work, revealing that our Network is growing both academically and in terms of actual numbers. In suggesting that now is the 'Time for Change', the Network and its members are well placed to make such change a reality. We look forward to seeing everyone in 2018 in Portsmouth. Indeed, why not bring a friend! The Higher Education landscape is so dynamic at present that groups such as our Network of Engineering Education Researchers are essential in enabling well-considered and innovative change to take place. Such change can only be of benefit to everyone!!



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# Section 1: A Time for Change – Making the Case

In drawing attention to some of the challenges faced by Engineering Educators within what it may be argued is an increasingly fractured Higher Education Sector, this first section provides an insight into colleagues' perceptions of some of the pedagogical issues that need addressing. Bringing together an eclectic collection of expert opinion and experience the papers provide a valid basis for the contention that 'it is time for change'.



## Practice – v – Professionalism: Challenging the Status-Quo!

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**KEY WORDS: Accreditation: Professionalism: Active Learning: Stereotypes in Engineering**

### SUMMARY

Taking a holistic perspective of modern-day engineering education, a meta-analysis of studies undertaken over the past 8 years was conducted with the intention of investigating how university level engineering education can better meet the expectations and needs of student engineers. Having conducted the analysis, the question of whether the *over-professionalisation of engineering is deterring young people from becoming engineers* arose. In seeking to answer this question, this short paper challenges contemporary ideology about the importance of Professional Body accreditation to engineering education. In doing it asks "*Are Engineers Professionals, Artisans or a synthesis of both?*"

### BACKGROUND / CONTEXT

University level engineering education is expected to provide future engineers with a wide-range of technical skills and competencies as well as an ability to understand and apply high level maths, science and other theory<sup>1</sup>. Yet, at a time when there has been unprecedented attention around the need to increase training and recruitment<sup>2,3</sup> 'Computer Science' and 'Engineering and Technology' have the highest 'subject-specific' attrition (drop out) rates in the UK university system (sitting in the 'league tables' at 11% and 8.3% respectively<sup>4</sup>). Yet reasons for this are ambiguous and questions of what can be done to encourage students to complete their studies in engineering largely unaddressed.

## STUDY AIMS AND OBJECTIVES

In aiming to identify how engineering education can better meet the needs and expectations of student engineers and society the study had three main objectives:

1. To identify key challenges facing engineering education today
2. To consider how more young people can be encouraged to study engineering
3. To identify how student attrition in engineering education may be reduced

## RATIONALE

Whilst issues of attrition in engineering education continue to cause universities problems, there can be little doubt of the crucial role engineers play within contemporary society. Often conceptualized as *Society's Problem Solvers*, today's engineers are tasked with developing solutions to a wide-range of complex international and local challenges that vary in nature from famine and poverty through to global warming, pollution and water-shortages<sup>5,6</sup>.

Taking the epistemological perspective that university level engineering education should prepare tomorrow's engineers to fill job roles that are yet to be created, use technologies that have yet to be invented, and solve problems that don't yet exist<sup>7</sup>; the underpinning study ontology conceptualized the "Professional Engineer" as being a highly capable individual who is able to bridge between Science-Society Nexus in an innovative, accessible and relevant manner.

## METHODOLOGICAL APPROACH

The meta-analysis utilised Ground Theory methodologies and used simple and axial coding to thematically analyse the distinctive findings of 12 Engineering Education Studies conducted over the preceding 8 year period. The findings from the meta-analysis were initially used as the basis for change within the institution in which both authors were employed<sup>8,9</sup>.

Five key areas vital for sustaining future engineering education programmes were identified. These are now briefly described.

## EMERGENT FINDINGS

- 1. Accreditation At The Expense Of Engineering Practice:** The meta-analysis suggested that students support professional accreditation and will opt for courses that are accredited by the professional bodies wherever possible. However, from an academic perspective, questions of whether institutions are sacrificing the underlying principle that an engineer is first and foremost a practitioner arose with some discussion about whether accreditation is an academic burden or a professional 'must'.

2. **Active – V – Passive Learning:** The study findings indicated that students and employers believe active learning in the lab and work-place to be of a much higher value than traditional class-based lectures. This reinforces arguments that undergraduate programmes need to embed a period of industrial work experience. It is time for universities to recognise that full-time education is not the only route into engineering. Other more practice based training programmes, including formal apprenticeships and on-the-job training are increasingly important and need to be embraced.
3. **Core Technical Skills:** From an industrial perspective the role that universities play in equipping young engineers with the skills and competencies to solve problems which have yet to arise was clearly evident throughout the meta-analysis. The question of how these skills should be defined and taught is one which is not easy to answer at a time when the curriculum is increasingly packed and resources are being cut.
4. **Key Transferable 'Competencies':** Softer transferable competencies such as an ability to communicate across disciplines or work in a team were identified as being vital tools for an engineer. One major concern relating to this was the question of how such competencies are assessed.
5. **Defining Engineering:** The meta-analysis revealed that confusion of 'what' Engineering is and 'who' Engineers are remains widespread within UK Society – particularly amongst young people.

## DISCUSSION

Having conducted the meta-analysis, the starting question of "*Are Engineers are Professionals, Artisans or a synthesis of both?*" has partially been answered in that the following definition is proposed:

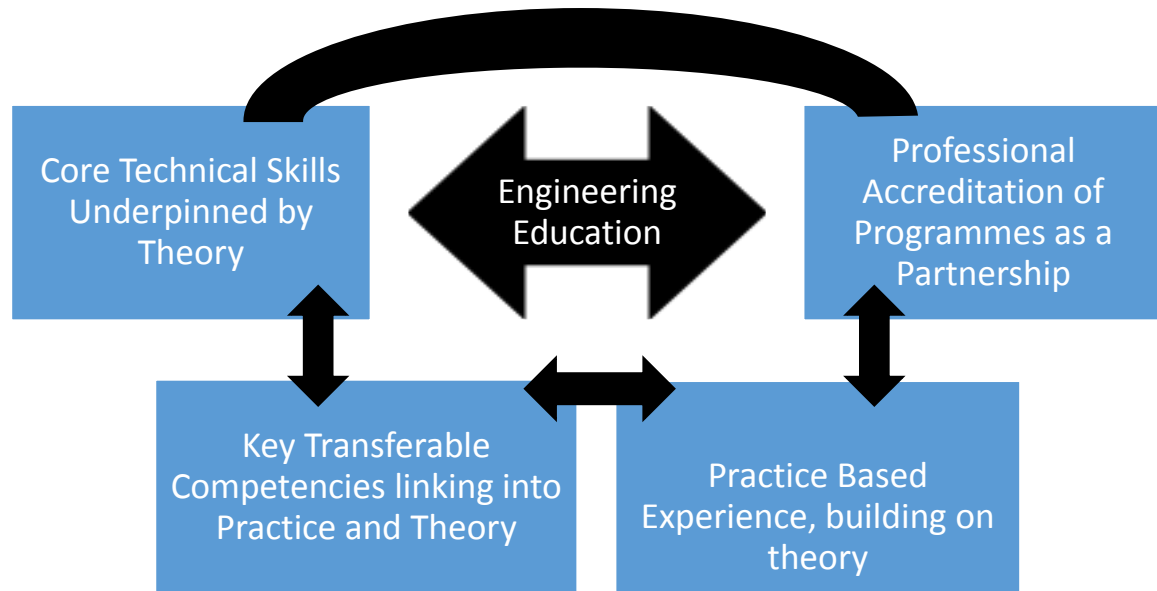
***In the 21<sup>st</sup> Century Engineers are Professional Artisans who in working innovatively at the frontiers of change, cross disciplines to bridge the gap between Science and Society.***

The above definition is built on the belief that if engineering education is going to meet the ever-increasing demands of current and future society, *then engineering education needs to place itself at the interchange between theory, practice and professionalism.* To simply focus on "The Engineering Professional" not only does engineering a disavour, it also potentially acts to deter future students who look at what is on offer and believe engineering is not for them.

Within this somewhat disputed arena it is suggested that Professional Accreditation does indeed have a role to play in engineering education. However, this should be balanced by an empirically grounded curriculum which has been purposefully developed so as to meet the wider needs of industry and society (as opposed to focusing on meeting the demands of the large engineering organisations).

Bringing the findings together a conceptual model was developed which depicts the centrality of engineering education in linking professionalism, theory and practice. Presented below in Figure 1 the model depicts the key conceptual underpinnings of engineering education.

**Figure 1: Engineering Education at the Interchange Theory, Practice and Professionalism**



This model, which has been used as a starting framework for a current study looking at how change may be successfully brought about within a University Engineering Education setting, places theory and practice on an equal footing whilst acknowledging that Professional Accreditation has a crucial role to play.

## CONCLUSION

In conclusion, Professional Engineer Artisans are key to the future success of our Society and Engineering Education is, in turn, key to the future success of the Engineering Profession. In many universities the desire for Professional Accreditation often trumps educational needs and student expectations, resulting in what may at best be described as a 'contested space' in which learning outcomes are largely unmet or irrelevant.

There has to be a better way forward. It is indeed, time to challenge the Status Quo!

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## How Do We Measure Ethical Perception and Decision Making Competences Among Higher Education Students?

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**KEY WORDS: Engineering Ethics, Ethics Education, Higher Education, RAEng**

### SUMMARY

Ethics is an integral element in the profession of engineering as engineers are expected to apply ethical standards and morals in their day-to-day professional commitments and practices. To promote and facilitate ethical awareness, Higher Education Institutes (HEIs) are now emphasizing Ethics Education in their core curricula and teaching. The objectives of such education are to train budding engineers to be work ready and ethically competent. However, for educators to teach ethics effectively they must understand students' awareness of ethics. Yet there are no consistent frameworks or measures implemented in Higher Education (HE) with which to determine or understand ethical awareness and decision making amongst engineering students. This study addresses this gap by proposing a new approach for educators to use in Ethics Education based on the Ethical Principles of the Royal Academy of Engineering (RAEng).

### BACKGROUND

Engineering Ethics is “the study of the decisions, policies, and values that are morally desirable in engineering practice and research” [1, pg 8]. Ethics and morality are the core fundamentals for a profession like engineering. Examples of where engineers could potentially face ethical dilemmas include the maintenance of industrial confidentiality as well as more individualistic issues such as responsibility towards public health and safety. It is therefore vital to teach ethical guidelines and standards to engineering students as part of their engineering education. Studies by Loui [2] and Atesh et al [3-4] have shown that students who are exposed to Ethics Education possess more confidence in identifying ethical issues and providing moral reasoning on a given circumstance. Such knowledge also boosts their familiarity and understanding of the moral codes, standards and ethical expectations associated with a profession.

### AIM AND OBJECTIVES



The RAEng is the UK's National Academy of Engineering and is known for promoting engineering excellence. The RAEng in collaboration with the Engineering Council and a number of leading Professional Engineering Institutions has recently introduced a set of codes known as the RAEng principles [5]; thereby establishing a standard for members of the engineering profession.

The main aim of this study is to examine whether the RAEng principles could be adopted in HE as part of Ethics Education and training.

Using the RAEng principles, this study proposes a new framework to measure the ethical awareness and decision making competencies among engineering students.

The objective of the study is to evaluate the feasibility of the proposed framework and its application in teaching ethics in HE.

## **METHODOLOGICAL APPROACH**

There are four fundamental principles in the RAEng Statement of Ethical Principles:

- Accuracy and Rigour
- Honesty and Integrity
- Respect for life, Law and the Public Good
- Responsible Leadership: Listening and Informing.

Each of these principles has a corresponding list of guided values and ideals. Based on these principles, 36 testable statements were derived into a survey using a five-point Likert scale. A pilot study was conducted among 54 students from the MSc Engineering Management in the department of Electronic Engineering, University of York for the academic years: 2015 / 2016 and 2016 / 2017.

The following questions were addressed and studied from the perspective of gender:

- **Q1.** How do students perceive the level of importance to the work they are expected to do as an engineer?
- **Q2.** To what extent do students agree with the development of ethical principles through their degree programme?

## **EMERGENT FINDINGS AND DISCUSSION**

The data analysis suggest some differences in the way male and female engineering students perceive the ethical roles and responsibilities. Differences were also noted in how male and female students rank the effectiveness of their degree programme in developing ethical understanding and awareness.

For Q1, which looked at students' perceptions of the applicability of the principles to the engineering profession, the results show that male students place the highest

priority on the '**Honesty and Integrity**' followed by '**Accuracy and Rigour**'. For females, it is '**Responsible Leadership**' followed by '**Honesty and Integrity**'. Surprisingly, both male and female students ranked '**Respect for Life, Law and Public Good**' lower than any other principles.

For Q2, the results show that both male and female students rank '**Respect for Life, Law and Public Good**' to be the top core principle that their degree programme is helping them to develop. This finding is rather surprising considering how students rated this element in question 1. Two important questions are raised:

- Does this mean that engineering students are failing to recognise the importance of the respect for life, law and public good to the engineering profession, despite a strong emphasis in their degree programme?
- Does the finding indicate a gap in academic and student perceptions of the engineering profession and of what is being taught as part of Engineering Education within HEIs?

## CONCLUSIONS & FURTHER WORK

The importance of ethical judgement and decision making skills in any profession including engineering has encouraged universities to prioritize Ethics Education in their curricula and teaching programmes. This study evaluated the use of a Professional Codes of Conduct for facilitating ethics awareness and discussion among engineering students. Based on the RAEng principles, this study is the first to investigate the feasibility of adopting a Professional Codes as an effective measurable framework within a Higher Education, Engineering Ethics setting.

Part of a PhD project, this pilot study has some limitations, particularly with regards to sample size. Further research is now being carried out using in-depth interviews and a larger sample to further investigate the results of the pilot.

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## A Study of Female Pupils' Perceptions of Engineering

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**KEY WORDS: Female, Engineering, Physics, Highers, A-Levels**

### SUMMARY

Focus groups were carried out with female S5/S6 pupils (age 16 to 18 years) to test perceptions of Engineering as a career. Two key variables were compared; an individual's *score* in terms of the Scottish Index of Multiple Deprivation (SIMD), and whether or not an individual was studying Physics at Scottish Higher Level.

### BACKGROUND

Despite great efforts in terms of engineering outreach in schools aimed specifically at girls from an early age, there has been little increase in the numbers of female students selecting to study Physics, Engineering and Computing subjects at Higher and A Level and University<sup>[1]</sup>. Strong gendered influences apply when female schoolchildren choose their subjects for Highers or A Levels, both to pupils and parents<sup>[2,3]</sup>. Additionally, there is a strong negative correlation between socio-economic background and choice of STEM subjects at the post-compulsory stage of education<sup>[4]</sup>

### STUDY AIMS

This study aimed to:

- Establish background information on female pupils subject and career choice in the area of Engineering;
- Test perceptions of Engineering; comparing those who chose Physics at Advanced (Higher) level and those who did not;
- Identify any areas of negativity and misconception;
- Make use of the findings to inform strategic change and ultimately attract more female candidates to UWS to study Engineering;
- Provide an empirical basis for the removal of Higher Physics as a pre-requisite qualification for studying Engineering<sup>[5,6]</sup>.

## RATIONALE

The purpose of this research was to examine female pupils' perceptions of studying a degree in engineering. It also examined girls' views of the fact that both Higher level Physics and Maths are usually required to enter an Engineering Degree.

## METHODOLOGICAL APPROACH

A number of focus groups, each comprising 4-6 female pupils at S5/S6 level were undertaken in 6 Scottish schools. Purposive sampling divided the focus groups according to whether the pupils had selected to study Physics at Higher level or not. The schools included in the sample represented a range of SIMD neighbourhood as shown in Table 1 below.

Table 1. Research Design representing range of SIMD neighbourhoods

|                                | High %<br>SIMD 20 School | Mid %<br>SIMD 20<br>School | Low %<br>SIMD 20<br>School | <b>Total</b> |
|--------------------------------|--------------------------|----------------------------|----------------------------|--------------|
| Pupils TAKING Physics          | 1                        | 1                          | 1                          | <b>3</b>     |
| Pupils NOT choosing<br>Physics | 1                        | 1                          | 1                          | <b>3</b>     |
| <b>Total</b>                   | <b>2</b>                 | <b>2</b>                   | <b>2</b>                   | <b>6</b>     |

Each focus group lasted for around one hour, with each group commencing with a set of Projective Techniques (Appendix 1).

Questions were structured around the basic Communication Model AIDA (Awareness, Interest, Desire and Action).

Data was analysed using Thematic Analysis.

## KEY FINDINGS

The findings may be summarised thus:

- Physics-choosers connected the subject with Maths, Engineering & Electricity;
- Those who had selected to study Physics often had a family member who was an Engineer;
- Those who had NOT taken Physics generally described Engineering using 'negative' terms including: *Difficult, Confusing, Hard*. They also described it using mathematical terms such as *Equations*;
- Those who had taken Physics tended to mention *Industry, Work, Labour and family members*;
- Those who had NOT taken physics tended to mention *Work, Manual, Relatives, Bridges and Planes*;

- The best thing about physics was felt to be *problem-solving, understanding, and experiments*, whereas the 'worst things' were *repetitive, confusing and memorising*;
- Pictures featuring a single professional male led to comments about *construction, blueprints, projects and architecture*;
- Picture featuring two males elicited responses on more manual aspects, such as *maintenance, factory work – and engineers*;
- The 'professional' female picture generated comments about *'looking at plans', construction and architecture*;
- The more practical picture of a female engineering elicited comments such as *fixing (circuits, electronics, electricity), technology, design and computers*;
- Perceptions of Science subjects, generally, were positive but Physics was viewed less positively, when compared with Biology and Chemistry;
- Physics was felt to be challenging – and linked to Maths: pupils believed if they did not have a strong Maths capability, they could not 'do' Physics. Comments included: *I don't like Maths and that's contained a LOT in Physics: Physics is for the 'good at Maths' pupils: You need to be REALLY smart – if somebody takes Physics, you know they're really clever*;
- Engineering elicited three broad responses: *connection to a relative who had this experience (either study or work): a notion that it involved 'heavy metal and machinery'* and was therefore of more interest to male pupils: An awareness that Engineering involves *a range of disciplines* (participants were uncertain as to what each type of Engineering involves, for example one young woman stated: *I don't know enough about it – there's different types of engineering and I don't know what they mean.*

## DISCUSSION

Pupils in Scottish schools choose which to progress to in the third year of their study (S3) during the second year (S2). At this stage, National 4 qualifications can be gained. During the 3rd year (S3) further choices are made regarding what subjects will be taken at S4 for their National 5 qualifications. Post-compulsory qualifications (Scottish Highers) are taken in S5/S6.

There did not appear to be a demographic distinction based on the SIMD: some pupils were certain of their prospective career destination and degree course by the age of 11 or 12, S1 (medicine, vet studies, teaching):

*"Even if I wasn't sure what I exactly wanted to do, I knew it would be in the science area – so I picked the ones I enjoyed doing and where I was getting best marks"*

Whereas others were more ambivalent:

*"I only really made up my mind right at the point when I was filling in the form!"*

Having determined broad subject areas, additional influences were felt to be potential career progression; these included areas of capability and those subjects that they enjoyed:

*"There's a sense of achievement when you get it right – it's a challenge and you did it!"*

*"I'm confident that I can do it and I'm satisfied when I do"*

*"It just interests me – I like it"*

Gender-stereotypes were evident – and Physics, in particular, was referred to as 'more for boys':

*"More for boys – engineering is their subject and they know more about it"*

*"Not for girls – more boys take it in this school"*

Additionally, there was evidence of some out-of-date associations with Engineering and 'heavy engineering', which dominated the West of Scotland up until the 1980s; when asked what they knew about Engineering, the following aspects were noted, with even some of those who had chosen to take Physics beyond the compulsory stage making this (family) association:

Table 2. A Comparison of Girls Perceptions of Engineering depending on the study of Physics

| Physics                                     | Non-Physics                              |
|---|--|
| Predominantly Male: Dad & Grandpa engineers | Heavy metal and big machinery            |
| Involved in everything                      | Manual job – not a graduate job          |
| Don't know that much                        | All male pupils want to do it            |
|   | Inventing things, like bridges           |
|   | Need to focus hard – things can go wrong |
|   | Mechanical, apprenticeship, manual work  |

It was also observed that irrespective of parents' educational background, parents had a strong influence and were heavily involved in their children's subject choice decision, with their focus being not only on what their children would enjoy but also the options that would benefit them in the future:

*"They wanted me to do what I enjoy but also to cover all the bases"*

*"They were keen for me to make the right choice – keep my options open"*

Those pupils who are the 'first in family' to attend university are less likely to be aware of Engineering as a university discipline. Pupils' siblings were also mentioned as influence, if a sibling had already chosen Engineering.

Pupils also described teachers as a positive influence and said that liked to hear the “back story” of their career choice and trajectory.

## CONCLUSIONS & RECOMMENDATIONS

In conclusion, where entry criteria to Physics and Engineering degrees are changed, it will also be necessary to raise awareness amongst school pupils that they can choose their career path at a later stage. The promotion of Engineering to younger pupils is recommended, particularly before subject choices are made. Any outreach activities need to be positively linked to a future career in Engineering.

Finally, the students’ perceptions of Physics as being a “hard” subject when compared to other subjects also links to a recent study which found that in being advised to “choose their best subject” girls are steered away from Physics at the pre-Higher stage, and therefore away from a potential Engineering career<sup>[7]</sup>

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# The Knowledge Mis-Alignment Between Engineering and Secondary School Technology Education

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**KEY WORDS: STEM, Teacher Knowledge, Secondary Education.**

## **SUMMARY**

The majority of secondary school engineering education is delivered within Design and Technology (D & T). There is a misalignment between the background subject knowledge of teachers responsible for delivering D & T and subject knowledge of engineering. This paper presents key findings from the London Schools Excellence Fund Study (Reference: LSEFR1210) which identified difficulties that some teachers have in accessing utilising science and math-based resources. The implications of this finding is that some pupils' do not receive an adequate level of engineering education in school; this in itself may be key to the number of pupils choosing to study engineering and technology beyond compulsory education.

## **BACKGROUND / CONTEXT**

A major part of English secondary school technology and engineering education is contained within the Design and Technology (D&T) curriculum. It therefore plays a crucial role in developing intrinsic motivation in pupils to study technology and engineering subjects beyond their KS3 compulsory education (Jones et al, 2017). The National Curriculum has been designed to provide pupils with an insight into engineering education at a young age. It contains many elements that engineering industry and academics desire pupils to know, including, materials, machine elements, electronics, programming, technical textiles and manufacturing processes to name a few. However, there is a clear disconnect between the ambitious curriculum and the average pupil's motivation and knowledge about the potential of engineering as a career. This study investigated the role that teachers' knowledge plays in this equation.

## **AIM AND OBJECTIVES / RESEARCH QUESTION(S)**

The aim of the study was to assess teachers' technological teaching competence of the KS3 National Curriculum. To do this the following research questions were investigated:

- What influence does teacher knowledge have on technology education?
- Are teachers confident in teaching the National Curriculum?



## RATIONALE

The data for this study were collected as part of the “STEM into Action with D&T” project funded by the Mayor of London’s Education Programme: London Schools Excellence Fund (London Schools Excellence Fund Reference: LSEFR1210) (Mitchell et al., 2015). Within this project, the Design and Technology Association and Mindsets provided teachers with a range of continuing professional development (CPD) activities and STEM project kits for pupils. This project was conducted to prepare teachers for delivering the 2015 National Curriculum by developing a range of resources and associated CPD to address teachers’ knowledge and experience gaps while enhancing existing skill levels and helping to develop confidence. This is important to engineering educational research as these teachers are responsible for the majority of the pre-university engineering education that pupils receive.

## METHODOLOGICAL APPROACH

Questionnaires were developed to generate data from teachers before and after the new STEM intervention with the intention of studying the effect of developing new STEM resources on teacher knowledge. Twenty-five competency statements related to teaching requirements of the D&T national curriculum were developed. The questionnaire asked teachers to self-assess their confidence, as a proxy to competence to improve response rates (Hargreaves et al, 1996; Williams, 2008) in teaching each of these competences using a 7-point Likert scale. Additionally, some qualitative data was attained covering the subjects not included in the main questions. The number of responses to the questionnaire is given in Table 1.

Table 1 Number of questionnaire responses and missing data

|  | Number of responses | Number of Complete Responses | of Missing Data |
|--|---------------------|------------------------------|-----------------|
| Start of project teacher questionnaire                   | 22                  | 19                           | 13.64%          |
| End of project teacher Questionnaire                     | 30                  | 24                           | 20.00%          |
| Both the start and end of project teacher questionnaires | 18                  | 15                           | 54.55%          |

Teachers Sampled:  $n = 33$

A mixed methods methodology was applied to the design of the questionnaire and the analysis of data. This addressed the strengths and weaknesses of both positivist and interpretivist data analysis (Johnson & Onwuegbuzie, 2004; Johnson et al, 2007). The Likert scale scores were analysed using non-parametric descriptive statistics of central tendency and variance. The pre and post-intervention data were compared using Wilcoxon Signed Rank Tests. Qualitative data were analysed using thematic analysis coding (Braun & Clarke, 2006). The processed data was analysed using selected



theoretical models of teacher knowledge (Banks et al., 1999; Mishra & Koehler, 2006; Shulman, 1987; Turner-Bisset, 1999)

## KEY FINDINGS

The demographic information about participants in this study revealed that the majority of the participants (61.90%,  $n = 21$ , 90% CI [44.32%, 79.48%]) had a BA Creative Arts and Design Degree. This suggests a similarity between the participants of this study and the estimated population data of D&T teachers (Jones, 2016). A z-test for two sample proportions calculated that there is no significant difference between the two proportions ( $Z = .410$ ,  $p > .05$ , two-tailed).

The median and Interquartile range statistics were used to identify teachers' strengths and weaknesses in STEM teaching confidence. On the seven-point Likert scales used, values  $<4$  were negative confidence and  $>4$  were positive confidence. The competences identified are shown in Table 2.

Table 2. Strengths and Weaknesses in teaching confidence

| Strengths in teaching confidence                               | Weaknesses in teaching confidence   |
|--|---|
| Q1. the classifications of materials by structure              | Q4. designing products with compound gear trains or other similarly advanced mechanical systems |
| Q9. using the correct technical vocabulary                     | Q7. building 3D textiles from simple 2D fabric shapes   |
| Q16. measuring and marking materials and components accurately | Q8. modifying the appearance of textiles using techniques such as dying or applique             |
| Q17. the use of CAM for scale of production                    | Q13. how to produce products that contain electronic sensors and outputs                        |
| Q19. using hand tools and manual machines                      | Q14. Programming  |
| Q23. health and safety   | Q15. incorporating microcontrollers into their products   |
| Q24. performing risk assessments                               | Q22. using CNC milling/turning/routing machines   |

A significant difference in start ( $n = 19$ , Mdn = 5.4, IQR = 1) and end ( $n = 24$ , Mdn = 5.6, IQR = 1) of project scores for all teachers was found using a Wilcoxon Signed Ranks Test of Exact Significance (2-tailed) ( $n = 15$ ,  $Z = -3.150$ ,  $p = .001$ ,  $r = .58$ ).

There was a significant increase in the scores of teacher confidence in technology teaching. The specific items that were improved across all participants were:

- Q13. how to produce products that contain electronic sensors and outputs ( $n = 15$ ,  $Z = -2.121$ ,  $p = .031$ ,  $r = .39$ )
- Q14. programming ( $n = 15$ ,  $Z = -2.232$ ,  $p = .016$ ,  $r = .41$ )
- Q15. incorporating microcontrollers into their products ( $n = 15$ ,  $Z = -2.251$ ,  $p = .016$ ,  $r = .41$ )

The key findings of qualitative questionnaire analysis are presented in Table 3. The thematically coded responses and the number of codes are shown.

Table 3. Coded analysis of responses to qualitative questions with number of coded responses

| Positive Feedback Code                  | Negative Feedback Code         |
|---|--------------------------------|
| Developing new schemes of work (14)     | Time Constraints (10)          |
| Developing pupils capability (11)       | Difficulties with projects (6) |
| Pupil interest (7)                      | Cost prohibitive (5)           |
| Discussing work with other teachers (7) | Teacher development (5)        |
| Professional Support (4)                | Engaging pupils (2)            |
| Awareness of subject (1)                | Content of projects (2)        |
|   | Unsustainable in school (1)    |

## DISCUSSION

The items classified as strengths are based on the making of products and using materials. The weaknesses are about the use of more advanced technology such as systems and control of mechanics and electronics, also the use of specific 3D manufacturing technologies that require CAD knowledge. The weaknesses in teaching confidence suggest that teachers are least confident about teaching the areas of technology that required mathematics and scientific knowledge. This work does not question teachers' ability to teach or their pedagogic knowledge, but does question if they have all the necessary subject knowledge to teach the more technological aspects of the D&T curriculum. Indeed, the fact that the majority of D & T teachers do not have a background degree in technology or engineering subjects is a major cause for concern as prior degrees are typically the dominant source of background knowledge utilised in teaching (Atkinson, 2011; Banks, 1997; Benson, 2009). Moreover, whilst teachers do appear to be attempting to improve their STEM knowledge, time often hinders their ability to do so. Simply providing resources for students will not directly help to improve teachers' ability to deliver STEM content.

## CONCLUSIONS & RECOMMENDATIONS

In conclusion, there is a misalignment between D & T teacher's knowledge of technology and what pupils need to learn in terms of engineering. To put it simply, school teacher's lack of knowledge means that school pupils are not sufficiently exposed to engineering ideas, concepts and knowledge. This has implications for engineering education at university, particularly with respect to differences in the level of knowledge engineering lecturers expect first year students to possess and what they actually know. Furthermore, this issue will continue to expand as fewer pupils choose to study technology subjects. Universities can use this information to assist in outreach and recruitment activities to understand why engineering is not being promoted in schools, as it is unknown to the teachers. The future impact of university outreach activists could be greatly improved by providing teacher development activities to improve schools' own ability to deliver engineering education.

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## No Engineering Capital? No Problem?? The Great Maths Debate

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**KEYWORDS: Engineering Capital, 'A' Level Maths, Pre-Requisite Qualifications**

### SUMMARY

Over the past 12 months or so there have been increasing calls to remove Mathematics 'A' level as a pre-requisite for studying Engineering at Degree level within UK Universities. Such calls are backed by some of the Professional Bodies as well as by a number of colleagues working in Engineering Education at University level. Anecdotally, it would appear that those mostly in favour of removing Maths as a pre-requisite qualification are from "Russell Group" Institutions which tend to attract those students more able to cope with the rigours of academic study. At the Symposium two key members of the UK and Ireland Engineering Education Research Committee debated whether Maths is really necessary to study Engineering at University level. Key to the debate is the question of whether students from widening participation backgrounds, including those from lower socio-economic groups and other 'non-traditional students' actually possess sufficient *a priori* 'Engineering Capital' prior to enrolment to enable them to succeed at University, particularly if they don't have advanced level of Maths knowledge when they start their course.

### BACKGROUND: NO ENGINEERING CAPITAL? NO PROBLEM??

Starting with the question '*Should GCE 'A' level Maths, or equivalent, be a pre-requisite qualification for entrance onto Undergraduate Engineering Programmes?*', this debate is underpinned by the somewhat unpalatable truth that many students arriving at university are totally unprepared to study Engineering at degree level. The reasons for this vary and range in nature from a notable lack of engineering context and content



in the High School Maths and Science curriculum<sup>[1]</sup> to suggestions that school leavers lack independent learning skills having effectively been 'spoon-fed' throughout their education<sup>[2]</sup>, meaning that they simply can't cope with learning at university level.

Other, more intangible explanations suggest that, upon entering Higher Education the majority of students are simply **not** equipped with the high levels of Social and Educational 'Capital' needed to succeed<sup>[3]</sup>. Contextualising this argument within an Engineering Education setting it would appear that few first year students possess sufficient levels of Engineering Capital when entering university. Whilst schools may provide 'STEM Enrichment Activities' these are often one off sporadic events which do little or nothing to nurture pupils Engineering Capital. It is not unreasonable to suggest that the majority of young people enrolled upon Engineering Programmes have not had many *a priori* life-enriching experiences, few have participated in STEM clubs, visited areas of scientific and engineering interest and the majority seem never to have even spoken to an engineer before coming to university!

Research conducted by two of the panel members in a research intensive, 1960's university (non-Russell Group) looking at first year students' perspectives of engineering found that most have no idea what an Engineer actually does or what Engineering is. They have little or no idea of what they will be expected to learn or the level of Maths and Technological / Specialist knowledge they will need to acquire. This means that upon arriving at university the only previous many new students have with Engineering is in the study of GCE 'A' level Maths or Physics. If Maths is no longer required to study Engineering, students could enter university even less prepared than they currently are. This in itself may potentially lead to increased drop outs and failure as students struggle to get to grips with a subject they are ill-prepared to study.

Conversely, students from more privileged backgrounds, many of whom have the opportunity to participate in extra-curricular STEM activities, enter university with higher levels of Engineering Capital and so are better prepared to study engineering. Thus, in theory, such students could perhaps cope with the rigours of the undergraduate engineering curriculum without having first studied Maths.

## **SO DOES IT MATTER?**

In a rapidly changing world where natural resources seem to be diminishing and international global challenges such as terrorism, climate change, poverty and sustainability appear to increase daily, the need for Higher Education to produce innovative, young Engineers able to solve society's ills has never been greater. Yet within this context the question of whether young people actually need to be able to understand and 'do' Maths to be good Engineers is one that remains largely unanswered. It seems colleagues either extol the virtues of Maths 'A' level, or believe it is unnecessary.

At the same time young people are increasingly savvy when it comes to **operating and accessing** new technologies and innovations but appear to have little inclination to actually understand the Maths and Science underpinning such advances<sup>[4]</sup>. Yet the very fact that students are technologically capable from an **operational** perspective

(if not from an epistemological or theoretical perspective) is raising the question “*Do all first year Engineering Students need to possess GCE A level Maths to study Engineering?*”.

Whatever the answer to the above question, there is little doubt that universities are struggling to attract enough young people onto Engineering Programmes. Figure 1 below shows the HESA data for the academic year 2014-15 <sup>[5]</sup>. This data reveals that Business Studies continues to be the most popular subject to study at university level with over twice as many graduates as Engineering.

**Figure 1: The Numbers of Students Graduating from UK Universities in 2014-15 in 5 key subject areas**

| <b>Subject</b>                         | <b>Undergraduate Degrees Awarded 2014-15</b> |
|--|--|
| Engineering & Technology               | 25435  |
| Medicine & Subjects allied to medicine | 52965  |
| Business Studies                       | 59725  |

**Adapted from HESA (2016)**

The above figures are of some concern in that they reveal that over four times as many students graduated from Medicine and Allied subjects, and Business Studies, than from Engineering. The reasons why students shy away from Engineering are complex and not all are centred on the need to study ‘A’ level Maths. What is clear is that there are enough intelligent young people to alleviate current and future shortages within Engineering – we just need to persuade them to study Engineering rather than Business, Medicine or another non-technical subject. The question then shifts from “*Whether Maths is really necessary to succeed in Engineering?*”, to “*How can we get more young people to choose to study Engineering in the first place?*”

**THE DEBATE: IS IT TIMES TO REMOVE MATHS AS A PRE-REQUISITE SUBJECT TO STUDY ENGINEERING**

Whilst some of the ‘elite’ Russell Groups have removed the requirement for GCE ‘A’ level in Maths and / or Science from their Engineering Programme Entrance Requirements, most universities have not. With the majority of young people entering university lacking in Engineering Capital, the tricky question of what should replace ‘A’ level Maths has not been considered.

The debate during the UK and Ireland Engineering Education Research Network consider this and the other questions. It looked at the issues from both sides of the argument invited colleagues to give their perspectives.

## CONCLUSION: THE DEBATE OUTCOME

The debate took place during the EERN Symposium in London, November 2017. Perhaps not surprisingly, in the time allotted it was not possible to air all concerns or to consider all the evidence. The one conclusion that did emerge was that there is no clear consensus amongst our community of educators, professional bodies, students and industrialists about Engineering students need to possess 'A' level Maths.

The debate sparked a great deal of interest, so much so that a more in-depth and inclusive debate is planned for the Spring 2018.

The debate continues....

... We look forward to the next installment... ..

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## How Important are Maths and other Entry Qualifications for Success in Engineering Undergraduate Degree Study in the UK?

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**KEY WORDS:** Engineering Education, Undergraduate Degree, Maths, Entry-Qualifications

### SUMMARY

This study undertakes a detailed evaluation of the relevance and importance of mathematics-related entry qualifications and teaching in the context of engineering programmes and curricula, engineering student progression through their degrees, and successful degree award.

### BACKGROUND / CONTEXT

Mathematics for engineering students is a widely discussed topic, both amongst those responsible for teaching Maths to engineering students, and by those responsible for engineering programme / curriculum design [1]. It is generally accepted that confidence in Maths is a necessary pre-requisite for success on most Engineering degree courses. It is less clear how best to encourage more school students to study appropriate maths in order to allow them access onto engineering degree courses [2]. In July 2015 the Royal Academy of Engineering published our *Pathways to success in engineering degrees and careers* report [3]. It highlighted a complex picture with regard to entry qualifications and degree success. Whilst slightly greater proportions of students with an A grade at A-level maths graduated with a first or 2.1 from both Bachelor's and Integrated Master's Degrees, First Class or 2.1 degrees were not restricted to those engineering students with the best A-level maths entry qualifications. Clearly the Engineering HE sector as a whole had successfully designed engineering curricula and support structures to cater for the wide variation in students' pre-University Maths-related qualifications.

The Pathways Study included a limited analysis of progression data for students who started their Engineering degree in 2007, which appeared to indicate that students with weaker maths qualifications on entry (particularly those with no recorded prior maths qualifications), had the highest non-continuation rates after the first year of study. Understanding this picture in more detail, with more recent data, a focus on entry and progression as well as graduation, including part-time and Foundation Year entry students, was considered a priority and is the basis of this current study funded by the RAEng.

### AIM AND OBJECTIVES

The project aim is to undertake a detailed evaluation of customised HESA student datasets to understand the relevance and importance of **mathematics qualifications** in the context of engineering degree programmes and curricula,



engineering student progression through their degrees, and success in achieving a good degree award. It also aimed to contextualise the data analysis by identifying examples of successful approaches to teaching Maths to engineering students and providing remedial Maths support.

## **RATIONALE**

The study hopes to provide the engineering community, including engineering academics and admissions staff, with a detailed picture of the importance and relevance of Maths and other entry qualifications to student success in engineering degree studies. It may also provide prospective engineering students with guidance as to appropriate entry qualifications for success in different HE sectors. Policy makers would also benefit from the analysis, particularly if approaches can be identified to improve progression rates in particular for disadvantaged groups.

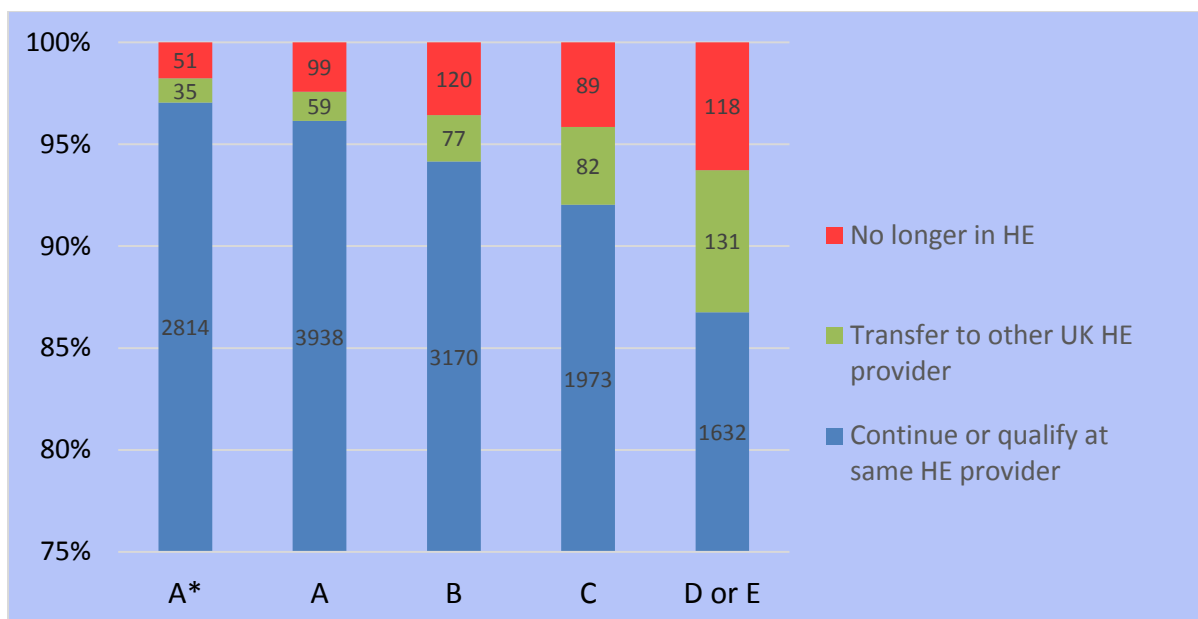
## **METHODOLOGICAL APPROACH**

Customised HESA datasets have been analysed for full-time and part-time UK bachelors and integrated masters students studying degrees with >60% engineering content in 2014/15 and 2015/16, including students entering engineering Foundation Years. This has included analysis of entry qualifications across and between different engineering programmes and Universities, plus progression data and graduate degree success data in the context of Maths-related entry qualifications. We have also compared Universities' published engineering-programme admissions qualifications (suitably anonymised) with the actual entry qualifications of the students they have admitted.

This project is very much *work in progress*, with envisaged completion by mid-2018. However, some initial analysis has been completed and is reported here. Discussions will follow with professional bodies, engineering academics and admissions staff representing HEIs from different University sectors, plus others involved in mathematics teaching and remedial support for engineering students, gauging their reaction to the findings of this study.

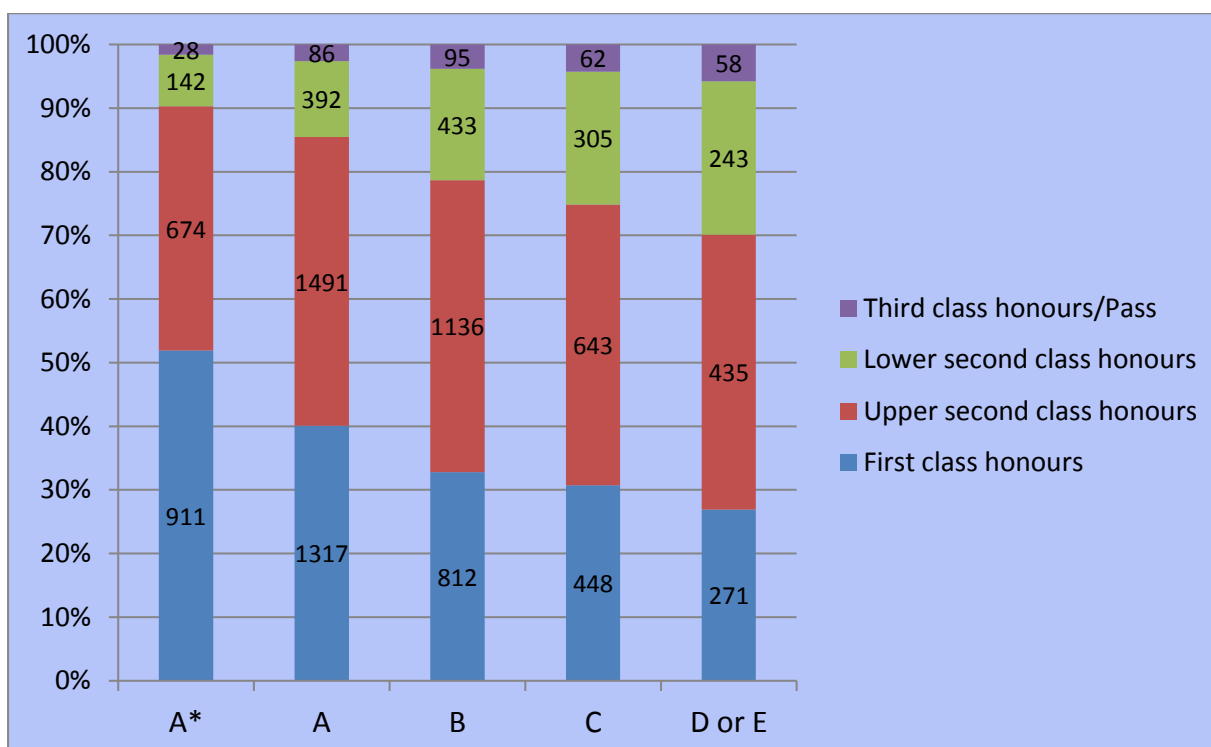
## **KEY FINDINGS**

Some initial quantitative findings of this *work in progress* are provided here. In 2015/16 there were just over 65000 full-time and 10000 part-time UK domiciled engineering students split roughly 60:40 between bachelor and integrated-masters degrees, of whom almost 87% were male. In 2016, just over 15000 of these students graduated, with about 35% gaining a 1<sup>st</sup> and 40% a 2.1. About 62% of engineering students had Maths A level or Scottish Advanced Higher as an entry qualification, with about 12% also having a Further Maths qualification. Just under 10% of students had entered via an Engineering Foundation Year.



**Figure 1: End-of-Year 1 Progression/Continuation rates for UK-domiciled Engineering students with different Maths A level grades. Numbers of students indicated.**

Figure 1 and Figure 2 show the Year 1 progression and final degree classifications, respectively, for 2014/15 and 2015/16 UK-domiciled engineering students with different Maths A-level entry grades studying on bachelor and integrated-masters degree programmes.



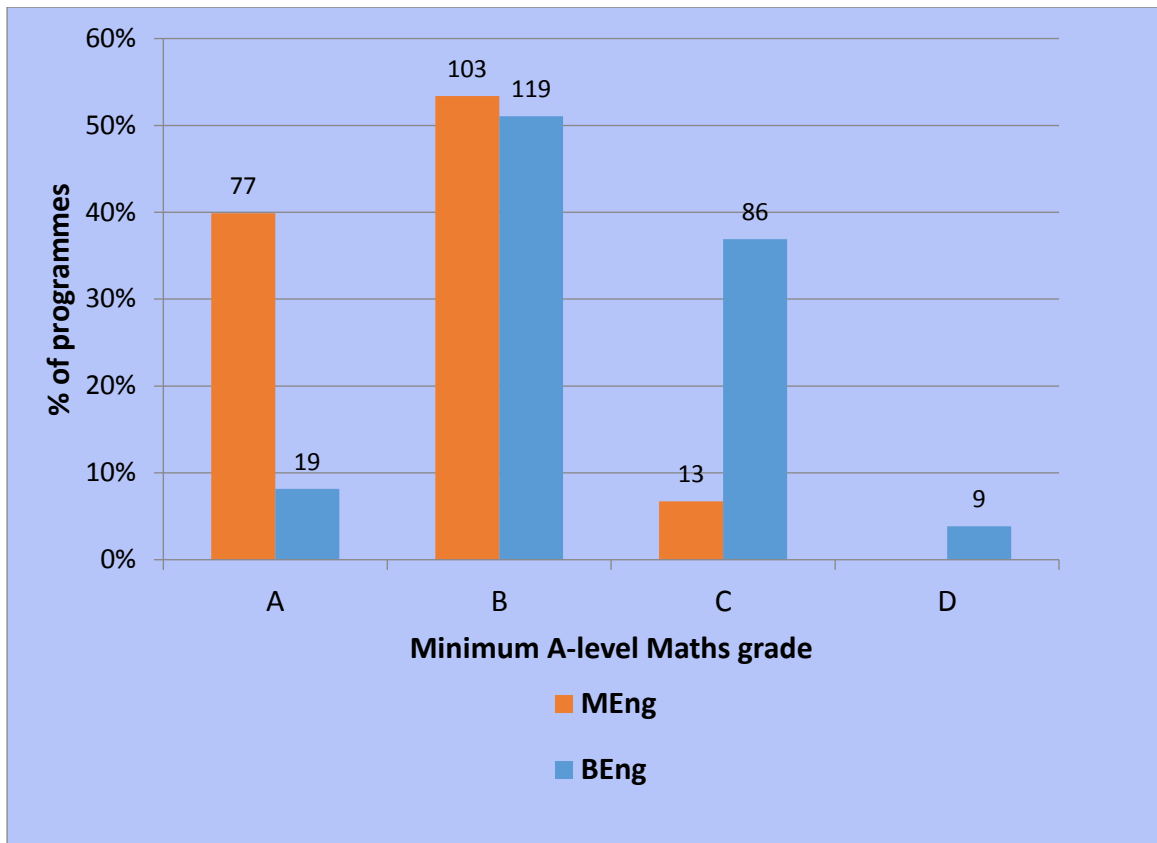
**Figure 2: Degree classifications of UK-domiciled Engineering students with different Maths A-level grades. Numbers of students indicated. Data excludes students on "unclassified" degrees.**

Only about 2.5% of engineering students who had entered their engineering degree with an A\* or A grade at Maths A-level left higher education at the end of their 1<sup>st</sup> year. 44% of such students gained a 1<sup>st</sup>, and 43% graduated with a 2.1. Progression rates and degree classifications declined for students with lower Maths A-level grades. Published admissions qualifications required for entry onto engineering degree programmes varies widely.

Our analysis of 195 MEng, 223 BEng and 34 BSc programmes in Mechanical, Aerospace, Civil and Electrical Engineering indicated the highest entry requirement in 2017 was A\*A\*A grades for an MEng programme with maths required at A\*. The lowest entry requirement was 80 (old) tariff points (CDD equivalent) for a BSc programme, with no requirement for A-level maths although GCSE maths at grade C was required.

Figure 3, overleaf, shows the minimum Maths A-level entry grades specified for the BEng and MEng engineering programmes. More than 90% of MEng engineering programmes have either A or B grades in Maths A-level as a published entry requirement. For BEng programmes, B or C grades are the most common expectation. Aerospace programmes have consistently higher entry requirements, whilst Civil Engineering programmes have slightly lower.

Analysis of the actual Maths A-level qualifications of students admitted onto engineering programmes was also undertaken, and showed considerable variation between Universities as to the extent to which the published Maths entry qualification was met by the students they admitted. For engineering programmes with an A grade in Maths A-level as an entry requirement, 82% of students admitted with Maths A-level met that requirement. However the percentage meeting the Maths A-level entry requirement dropped to 70% for programmes with a B-grade requirement, and 58% for a C (58%) grade, clearly reflecting the difficulty some Universities have recruiting students with good Maths A-level grades.



**Figure 3: Minimum Maths A-level entry grades published for entry into BEng and MEng engineering programmes. A\* grades included in A. Number of programmes in sample is indicated in each case.**

## DISCUSSION

There is clearly a significant variation in progression rates, and degree classification grades, for students admitted with different Maths A-level qualifications. There is also significant variation between Universities in the Maths qualifications of students admitted onto their engineering programmes. There are significant numbers of students admitted onto engineering degree programmes with A-level maths grades less than that recommended for admission, including significant numbers admitted without a Maths A-level or Scottish Advanced Higher. Whilst students admitted with the highest Maths A-level grades do appear to progress and graduate with better degree classifications, further analysis is being undertaken to clarify the extent to which this is significant. We are extending the analysis to include other entry qualifications including BTEC, Foundation Year entry routes, and analysis of the data in the context of University sector, gender, ethnicity and socio-economic background.

## CONCLUSIONS & RECOMMENDATIONS

As this is a *work in progress*, it is somewhat pre-emptive to make firm conclusions or recommendations, which will be presented in future publications.

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## **Meta-analysis and review of the use of Artificial Intelligence and Learning Analytics within Engineering Education at University level.**

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**KEY WORDS: Intelligent tutoring systems; Learning Analytics, Meta-analysis, Engineering Education, Learning gain.**

### **SUMMARY**

Despite evidence of its usefulness, the use of Artificial Intelligence (AI) based Intelligent Tutoring Systems (ITS) in Higher Education (HE) has recently been questioned. There are calls for leveraging human intelligence as well as amplifying it through analytics and data mining techniques instead. Learning Analytics (LA) and Educational Data Mining (EDM) in HE have received great amount of attention in recent years to support and enhance human intelligence. This paper presents a cross-topic review in order to evidence 'what works' and the achievements of these technologies within the context of Engineering Education. The review found that recent applications of LA and EDM within Engineering Education hold promising for future systems. However, cross-pollination between the well established ITS field with emerging field of LA and EDM technology in education as opposed to parting ways may help improve their combined impact.

### **BACKGROUND / CONTEXT**

A qualitative systematic review of LA and EDM by Papamitsiou & Economides, (2014), reported an overlap in these two areas. But despite noting an additional overlap with AI based systems in education they did not include such work in their review. Their paper presented algorithmic and pedagogical classification of LA interventions but the evaluation of its effectiveness was not presented. The Learning Analytics Community Exchange (LACE) review report by Rienties & Rivers (2014) also included ITS, such as Auto Tutor, alongside ways to collect and make sense of multimodal data for LA purposes. This review also did not include a meta-analysis of the effectiveness of such systems in HE. Whereas a meta-analysis of ITS by Ma et al (2014) did just that, examining the entire education sector (N=14,321 students, k=107 studies) with an Effect Size (ES)=0.41 and Confidence Interval (CI) of (0.34,0.48).

AI based ITS and LA were linked together in a review where the authors called for researching pedagogically useful indicators for prediction purposes (Chatti et al, 2012). Whilst another, very elaborate meta-analysis reported an ES of 0.75(SD=0.36) of ITS in post-secondary education (k=27) (Kulik & Fletcher, 2015). Whilst in a narrative review on LA, several studies that involve the above intervention types were identified by Sin & Muthu (2015). Yet despite the fact that many previous publications have linked these technologies, there has been no attempt to compare their effectiveness side by side.

It is this gap in knowledge that inspired the author to carry out a unique cross-topic review with special attention given to the intervention effectiveness and their pedagogical underpinnings. By summarising the findings of the part of the review that focused on the Engineering Education literature this short paper builds on and adds to current debates in this area.

## **AIM AND OBJECTIVES / RESEARCH QUESTION(S)**

Part of a much larger review, the aim of the study reported in this paper was to systematically review the literature on the use of AI and LA systems within Engineering Education (EE). It was intended that the research findings would inform future research directions and trends.

### **- *Overarching research question 1:***

*How do Engineering academics and students benefit from ITS and or LA based interventions within HE?*

### **- *Sub questions (focussing on specific outcomes):***

1. *Does student performance improve when using such systems within Engineering Education?*
2. *What are the other outcomes for Engineering academics and students related to such systems?*

## **RATIONALE**

Using the PICO framework, the review set out to show how such systems can help students and academics within the context of Engineering Education. The intention was to document the combined effect size of such technological interventions in order to compare and contrast the two (LA and AI) based interventions.

## **METHODOLOGICAL APPROACH**

A systematic review “sums up the best available research on a specific question” (Campbell Collaboration, 2012; Pickering & Byrne, 2014). It uses “an explicit search strategy, clear inclusion/exclusion criteria, systematic coding and analysis of included studies and meta-analysis (where possible)” (Campbell Collaboration, 2012) and is viewed as the gold standard in knowledge synthesis (Boland et al, 2013). A convergent parallel mixed-methods research approach was used to discover, articulate and confirm the trends within the two fields (Creswell & Plano Clark, 2011). This approach benefits from the statistical power and formalism found in quantitative studies, through the use of a Meta-Analysis, to test some of the exploratory findings from the qualitative analysis of the data. At the interpretation stage this can help identify of gaps in the literature. Additionally, some explanatory findings from the



qualitative analysis can help identify reasons behind the success or failure of interventions.

## KEY FINDINGS

The findings show the effect size derived using a meta-analysis of all engineering based studies selected. A moderate effect size,  $ES=0.631$ , significant in nature was found. Variability within the data set was high ( $I^2=72.7\%$ ). This called for a moderator analysis to explore sub-trends. Coding of studies prior to the meta-analysis was used to group studies under two categories, namely those that are cognitive pedagogy based and those that are based on more than one pedagogies including behaviourist and constructivist.

The results shows that ITS that have cognitive underpinnings are more common and have a smaller ES compared (0.416) to ITS & LA systems that have multiple pedagogic underpinnings (0.680). However, the difference is not significant, both show moderate effect. LA systems are based on multimodal data sources and are therefore underpinned by multiple pedagogies and they benefit from human interventions (which can vary and needs defining/monitoring).

## DISCUSSION

Contrary to the hype around LA, ITS and LA based interventions are similar with regards the effect size on student learning. The review results show that there is no need to part ways and drop the research of decades on intelligent tutors, in favour of the recent advances in Learning Analytics.

## CONCLUSIONS & RECOMMENDATIONS

A statistically significant and moderate ES is observed both when using ITS and LA in EE to improve student performance. This suggests that interventions based on these two different technologies have comparable and somewhat limited effect on student performance. Hybrid systems, using the two technologies in one system, should therefore be developed and evaluated for their impact on student performance. Taking inspiration from some of the LA interventions, AI models that are based on large standardised multimodal datasets, including biologically and pedagogically inspired ones could help improve the ES figures in future. LA and EDM insights and “guardian” like humans could over time enhance these AI models. In a similar vein, the autonomy afforded by ITS systems could help reduce the burden on human action required after the insightful trend analysis seen in LA and EDM systems.

In conclusion, given the results of this study, pursuing LA or ITS alone may prove counterproductive.

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# Section 2: Innovating Practice through Research & Curriculum Change

This second section brings together a collection of papers grounded in different stages of Engineering Education Research; with some discussion very much a work in progress whilst some reflects the findings of longitudinal studies at PhD level and above. By adopting an empirical approach to Engineering Education colleagues across the EER community are leading the way in promoting evidenced-based practice and policy.



## A Longitudinal Study of Middle Eastern Women's Experiences Studying Engineering Abroad: Emerging Results

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**KEY WORDS: Student Support, International Students, Problem-Based Learning, Middle Eastern Women, Phenomenology**

### SUMMARY

What is it like to study engineering in Ireland when you are female and you come from somewhere far away, in the Middle East, which has different social customs and norms? What is the lived experience? What aspects of the experience are common to all Middle Eastern women enrolled in your course? As education researchers, we aim to understand the essence of the experience such women have had studying engineering in Ireland; we focus on what life has been like for them and what unique challenges they have faced that may be invisible to us as instructors.

In this work-in-progress, a longitudinal study that uses phenomenological methods, our research team investigates and interprets the experiences of eight women from Kuwait and Oman who started the four-year Bachelor of Engineering program at Dublin Institute of Technology (DIT) in 2014. Of the eight, seven were still enrolled in 2018 and in their fourth year of university-level study. One participant had returned to her home country to complete a degree in an unrelated field, but the seven others were on-track to earn engineering degrees. Across this four-year period, we conducted 15 interviews with these eight students. The lead author had opportunity to observe their participation in PBL design projects (that we were not assessing) during the students' first year. We report preliminary findings of our analyses in this conference paper.

### BACKGROUND / CONTEXT

The two lead authors started this line of research together in 2014, with a particular interest in students' experiences of collaborative and problem-based learning (PBL). We began by interviewing a broad group of female engineering students in multiple locations across Europe. The selected locations—Ireland, Portugal, and Poland—reflected a range of cultural values and provided good access to participants. During the Academic Year 2012-13, we conducted semi-structured interviews 60-90 minutes in length with 46 female engineering students studying various types of engineering (see Table 1). Of these, 28 were studying in Ireland, 11 in Poland, and 11 in Portugal.



| <b>Table 1: Participants in Overall Sample</b> |               |                   |                     |
|--|---------------|-------------------|---------------------|
| <b>Interview Location</b>                      | <b>Native</b> | <b>Non-Native</b> | <b>Total Number</b> |
| Ireland  | 10            | 14                | 28                  |
| Poland   | 11            | 0                 | 11                  |
| Portugal                                       | 10            | 1                 | 11                  |
| Total  | 31            | 15                | <b>46</b>           |

Our analyses of the overall set of interviews conducted in AY 2014-2015 indicated that international students from Middle Eastern countries (n=8) were having a much different experience in European higher education than the other women. Their experience differed from native-born women (n=31) and also from international students from other parts of the world (n=7). In response to this finding, we conducted follow-up interviews with the Middle Eastern women in our overall sample.

### **AIM AND OBJECTIVES / RESEARCH QUESTIONS**

We aim to develop a deeper understanding of the lived experience of this sub-set of students because we believe this particular group faces unique barriers when studying STEM subjects in a Western country. We wanted to identify aspects of the experience that we and other educators might be overlooking. Finally, we wanted to help ourselves and other educators do a better job supporting this sub-set of students. We chose to let the findings arise from the interview data provided by students, rather than start with a pre-determined theory or framework, and this is consistent with the phenomenological methodology we have been using from the outset of this study. Consistent with this approach, the research questions take final form as the data are coded and better understood. In that the participants were encouraged to raise their own topics during interviews, we had to examine the data to identify what questions could be answered from these data. Based on initial analyses, we were able to refine our original research questions, ultimately asking:

- Q1) What prior experiences led the women to study engineering? What has the phenomenon of engineering study been for these women?
- Q2) Regarding Problem-Based Learning pedagogies, what has been their experience with collaborative learning and learning in groups? To what degree have PBL pedagogies helped support our participants?
- Q3) Regarding the balance of challenge and support (Sanford & Adelson, 1962), what difficulties and challenges have the women experienced? What moments of enjoyment or satisfaction? To what degree have the challenges and supports balanced effectively?
- Q4) What guidelines can be put forward for engineering educators as findings of this study?

## METHODOLOGICAL APPROACH

As noted above, we interviewed the entire cohort of Middle Eastern women who joined our DT066 common core Bachelor of Engineering program in September 2014. We conducted initial in-depth phenomenological interviews with them (and 38 other women) in 2013. As a result of initial findings, we conducted follow-up interviews with the sub-set of women from the Middle East in 2017. At this point, 15 have interviews conducted with Middle Eastern women studying on this course in Ireland and 13 of these interviews have been transcribed in full. We coded these 13 interviews using NVivo, and in the process, we identified several pertinent themes and developed some preliminary recommendations for educators.

As is common in phenomenological studies, we conducted open-ended, semi-structured interviews; the interviews were conversational in nature to allow topics most important to the participant to rise to the forefront. The interviewer made sure to address all the topics on the interview schedule, with most of these arising in the normal course of the conversation. The initial interviews started with the question, "How have you been getting on here in Dublin and at DIT?" Follow-up interviews began with the question, "When you think back over your past years here in Dublin and DIT, what stands out most in your mind?" The initial interview invitation indicated that we had interest in collaborative learning.

In keeping with phenomenological methods, we let the findings rise from the data. We did not start with an existing theory or conceptual framework as one would if using another methodology, such as critical race theory, which could also yield interesting insights. In this case, we are seeking to know what this group of students has experienced, without presupposing that their experience mirrors any existing theory, or even that it necessarily needs to be changed. We have, however, assumed that there are aspects of this group's experience that we have been overlooking and can better understand through careful, systematic analysis. We are using the transcendental phenomenological approach defined by Moustakas (1994) to produce a refined synthesis regarding meanings and essences of their experience.

Moustakas' (1994) book describes a highly structured approach that we have implemented previously and that we deemed appropriate to meet our research goals. This methodology yields textural and structural summaries that we will ultimately use to create composite statements reflecting the overall essence of the experience on specific themes that have arisen and have informed our research questions. An example of this is the question on challenge and support, which stems from an existing theory by Stanford and Adelson (1962) that appeared relevant to our participants' narratives.

As per Moustakas' methodology, the textural summaries will explain "what" happened whereas the structural summaries will explain "how" the phenomenon was experienced—which can happen in a range of ways. We will explore similarities and differences in the way they perceived and interpreted their experience, as indicated in Table 2.

| <b>Table 2: Moustakas' (1994) Methodology for Transcendental Phenomenology</b>  |   |
|---|---|
| <b>Textural</b><br><i>What</i> happened? What did participants experience with regards to this phenomenon?  | <b>Structural</b><br><i>How</i> did participants experience this phenomenon? How did it feel? How did they understand and conceptualize it? |
| <b>Composite</b><br>What was the <i>essence</i> of the participants' shared experience?<br>This combined statement reflects a synthesis of textural and structural aspects. |   |

Creating these summaries will help move us toward creating a final, composite statement that synthesizes what we've learned. As such, developing the textural and structural summaries helped us build valid, well-synthesized interpretations that equate to Moustakas' composite statement. As mentioned earlier, we aligned the research questions to Moustakas' approach after finding that some of research questions had clear textural and structural aspects and that other research questions required synthesis (of the sort commonly found in the composite statement). This was done in an iterative process wherein the content of each interview was broken down into invariant meaning units (Moustakas, 1994) and these units were sorted into clusters. The research questions were then refined based on what we could answer via the narratives provided.

## EMERGING FINDINGS

To date, coding and analyses have focused on the first research question, which involves two parts. We provide examples to show the direction of our future work.

Q1a asks what prior experiences led the women to study engineering. Common themes arose regarding earlier schooling, including: school context, decisions about career trajectory, the option to study abroad, choosing Ireland, experiencing foundation studies and preparation work, and choosing DIT.

*School context* is a theme that has to do with texture, or *what* happened. Interview data indicated all but one participant had come from gender-segregated schools in Oman and Kuwait. During childhood, participants did not study alongside or socialize with boys outside their immediate family. All participants had studied English in school, but only a couple had taken any academic subject in English during primary or secondary school. They did study maths and physics in school, but learned the terms of science in Arabic. Parents had important supporting roles—encouraging their independence and higher education.

*Determining career trajectory* is a theme than has more to do with structure, or *how* engineering education was experienced. Under this theme, we discovered that enjoyment of maths and of practical (hands-on) learning encouraged participants to consider engineering. Selecting an appropriate sub-field of engineering was an important concern in secondary school—and even earlier for many. They perceived

that engineering was a good career for women and that engineering jobs in their country would be plentiful. Consideration of job opportunities was crucial to their decision-making, and they saw their governments encouraging high school graduates to pursue engineering degrees. Many had parents encouraging them to pursue subjects that would provide them independence in the future, with both medicine and engineering considered good choices. Several selected engineering after attempting to enter medicine and either not enjoying it or not being admitted to study; some experienced disappointment at not getting the scores to pursue medicine, while others realized they preferred maths and engineering technologies.

Participants received valued and trusted input on career choice and study options from close family members, particularly siblings and cousins with prior experience studying related topics, often in the UK or Ireland. Early on, participants envisioned themselves going back to their home country to work following their studies. They planned to work in manufacturing, oil and gas, or utility companies. Many anticipated balancing work, marriage, and motherhood in the future, and planned to live with their parents until marrying. With regard to future employment, they anticipated working in teams with men as well as women, and with people from many parts of the world. They envisioned that work would be conducted in English and that they would need to communicate effectively in English in order to work as engineers, even in their home country.

Q1b asks what the phenomenon of *learning engineering* been like for the women. With regards to what happened (i.e., the texture), all engineering students in the B.Eng. program take the same first year classes (called the common core) which provide a sample of the three major streams of engineering available for specialization: civil and structural; mechanical and manufacturing; and electrical and electronics. At the end of the first year, after completing basic course work applicable to all streams as well as a hands-on team-based design project in each of the three streams, each student selects and enters one of these streams, often making a more fine-grained selection of speciality within the stream after year two. Participants made reference to this process in their interviews; they described their relationship to and reflections on the process.

*How* this process was experienced (i.e., the structure of the experience) is of interest to us. For this group of students, adapting to the style of teaching at DIT—and the way of learning promoted by the institute and the college—required some adjustment but most found ways to navigate the system satisfactorily. They described their first year tutors as extremely helpful and supportive—as people they frequently visited with questions. All the women in the cohort/sample stayed on at DIT beyond the first year. It wasn't until the end of the second year that one participant left engineering and DIT, when she provided her only interview two days before departure, and saying "*in my case I didn't used to understand the classes (...). I was in classes that didn't make any sense to me.*" She had avoided the interview previously since she felt unengaged and disinterested and felt she'd have little to offer. Although the others often had difficulty understanding, they typically found ways to connect with what was being said, but for her it was a constant hardship and struggle to try to learn things she found unappealing.



For all the women in the sample, the presentation and delivery of material in class provided challenging. Participant descriptions focused on: how material was communicated, practicing new techniques in class / lab, learning through observation, asking the teacher for help, and resolving concerns about marking/grades. We identified several themes relevant to Q1b, "What has the phenomenon of engineering study been for the women?" These were: presentation of material in class, making sense of content presented, studying and practicing new material and skills, asking peers for help, experiencing the common core and choosing a sub-field, and considering an exit from engineering. We have summarized the results for each of these themes.

## UPCOMING WORK

As our analyses continue, we will create summary statements aligned with each research question. We will continue to integrate fundamental principles of Moustakas' (1994) method. For textural analysis, we will utilize Moustakas' techniques of: (1) bracketing or *epoch* (setting aside preconceived ideas); (2) horizontalizing (treating every statement as equal in value to every other statement); (3) clustering horizons into themes; and (4) organizing the horizons and themes into a coherent textural description.

For structural analysis, we will utilize Moustakas' (1994) technique of imaginative variation. This will allow us to consider "alternate outcomes" to help validate our interpretations and distil findings down to the core essence. Steps in the process of imaginative variation involve: (1) systematically varying structural meanings (about individual and shared perceptions) that underlie their experience of the phenomenon itself; (2) identifying themes and contexts that underlie and allow the phenomenon to appear; (3) giving consideration to universal structures such as "time, space, bodily concerns, materiality, causality, relation to self, or relation to others" (Moustakas, 1994, p. 99) that precipitate the thoughts and feelings people experience alongside the phenomenon; and (4) pinpointing examples that adeptly illustrate structural aspects to create a structural statement.

In creating composite statement to address the more complex research questions, we aim to describe core aspects of the phenomenon that could not be changed or altered without affecting the overall experience described by participants. Such a composite will help us answer two of our sub-questions:

Q2b) To what degree have PBL pedagogies helped support our participants?

Q3b) Regarding the balance of challenge and support (Sanford & Adelson, 1962), to what degree have the challenges and supports balanced effectively?

Through this structured process of analysis, we intend to derive a list of recommendations:

Q4) What guidelines can be put forward for engineering educators as findings of this study?

## **EMERGING RECOMMENDATIONS**

Although Q4 cannot be answered accurately and fully prior to careful and iterative analysis, we have outlined our emerging thoughts on the subject, derived through observation and interaction with the sample group. We offer the following, preliminary recommendations to aid international educators wishing to understand and empathize with such students and to do an effective job communicating with them and supporting their education. Preliminary recommendations can be summarized under five headings: consider approachability, facilitate peer learning, reduce distance, consider language, and balance teams.

### **Consider Approachability**

We recommend teachers project a sense of approachability (via eye contact, recognizing individuals, getting to know names, and welcoming questions) and availability (letting students know when and where people are available to help and preferred ways to reach these people/the teachers).

### **Facilitate Peer Learning**

Teachers can promote collaborative learning by helping the students see their cohort as a team and their classroom as a laboratory for learning together. Consider how your classroom can become more interactive, and what opportunities exist for students to teach each other some of the content (e.g., pairing students so the stronger students share what they're learning, and they learn to say it in new ways). Explicitly discuss the importance of mentors, how to identify them, and the need to cultivate relationships.

### **Reduce Distance**

Break down the distance between student and teacher by making sure that career mentoring and personal advising are available and your students know where and how. Encourage students to take risks and see failure as a step toward success.

### **Consider Language**

Answer questions using different words than you used to present the content, in case there's a vocabulary issue. (Students have to connect new content to prior learning and may have used drastically different vocabulary in the past; saying the same thing over again in the same way does little to help.) Check for communication/tacit knowledge issues. Pose some questions to check that they understand basic background concepts and can connect what you are saying to any concepts they already understand or experiences they have had. While they may have foundational knowledge, they may not be making connections that educators or native-speakers make implicitly. Also consider that foreign students may need a bit more definition about a project brief than native students before they can get started on an assignment. Local students may understand implicitly that you want a report as

opposed to a model or a strategic plan, or the type of chart or graphic convention you're using, whereas foreign students must make far more inferences and can get lost in translation.

## **Balance Teams**

As a result of our observations we now diversify teams as much as possible. When assigning groups, we now take into account gender, national/non-national status, attendance records and/or performance on past projects. We aim to have students work on projects with many different students in their first year. We assign teams for diversity as so as not to isolate anyone as the only female or only minority student in the group (e.g., our participants often felt their ideas were ignored by all-male teams, and they valued having some one more like themselves—whether female or speaking their own language—to bounce ideas off before posing them to the whole team so that the idea would be strong enough to be taken seriously and to contribute). When students are unfamiliar with each other, we provide ice-breakers to help them get to know several people before assembling their teams.

It is important to recognize that minority students typically feel uncomfortable asking mainstream students to be in their group. Nevertheless, all participants in our sample wanted to work with native English speakers—every participant brought this preference up.

We recommend providing group assignments where the group is selected by the teacher-selected as well as opportunities to work in student-selected project groups. Monitor engagement by observing teams in action and provide feedback on team dynamics. Give students guidance in good practices in teamwork and project management, and model good decision-making practices whenever possible.

## **CONCLUSIONS**

Overall, we believe we are developing crucial understanding of how this group of students navigates through a higher education engineering program and what unique challenges, opportunities, joys, and frustrations they face. By following Moustakas' (1994) structured process to the greatest extent possible and staying true to the data we have collected, we aim to provide valid findings to the research questions identified above and to report these in an international recognized education journal.

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## Describing Graduate Engineer Skills

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**KEY WORDS: Skills, Professional, Engineering Education**

### **SUMMARY**

This study found a method to describe the skills required for solving complex problems in industry and developed an evidence-based description. This description is now used to teach these skills during a Masters programme. Further work is required to extend the identification and description of generic skills associated with complex problem solving.

### **BACKGROUND / CONTEXT**

As part of a larger study investigating professional skills development during a one-year Masters programme the most significant problem found was an inadequate description of the skills to be taught. The particular skill set investigated were those required to solve complex problems found in industry. These skills are particularly important as during the Masters programme, students undertake four, two-week placements as a pair at different companies, where they are required to analyse a complex problem and propose a solution. These placements are referred to as Short Industrial Placements (SIPs).

Describing skills is probably a pervasive issue in Engineering Education. Subject Benchmark Statements e.g. Engineering (QAA 2015) provide a picture of what graduates might reasonably be expected to know, do and understand at the end of their degree. This is captured in a Programme Specification Documents and the 'do' aspect is associated with skills. These descriptions are typically high-level statements and lack sufficient detail to inform teaching and assessment.

### **AIM AND OBJECTIVES**

This study set out to find a method of describing skills required for solving complex problems in industry and then develop an evidence-based description that could be used to teach these skills.

## METHODOLOGICAL APPROACH AND RESEARCH QUESTION

An Engaged Scholarship methodology (Van de Ven 2007) was applied, which combines a mixed methods approach with a systematic process that links theory and practice as well the views of multiple stakeholders. This approach had been determined for the larger study (Shawcross and Ridgman 2017).

The problem formulation process found that skills can be determined if both a task and its context are known (Shawcross and Ridgman 2014) and that task frameworks have been effective in describing what graduates need to be able to do in practice (Dowling and Hadgraft 2013). So the research question identified was:

*"What tasks contribute to solving complex problems in industry?"*

A variance research design was applied to compare frameworks generated from literature with evidence in practice. Four cycles of action research were undertaken so that evidence was collected from eighty placements in one academic year. As a result of this research, a high-level task framework containing 17 task domains was identified of which 12 were 'process-stages' that described the solving of complex problems in industry (Shawcross and Ridgman 2014) – see Figure 1 below. The remaining 5 task domains appeared to be operate throughout a SIP and relate to generic areas including 'work with others' and 'manage the project'. These 'through-SIP' domains were found to be different in nature to the 'process-stages' so further work was undertaken to investigate these.

### 12 process-stages + 5 through-SIP domains

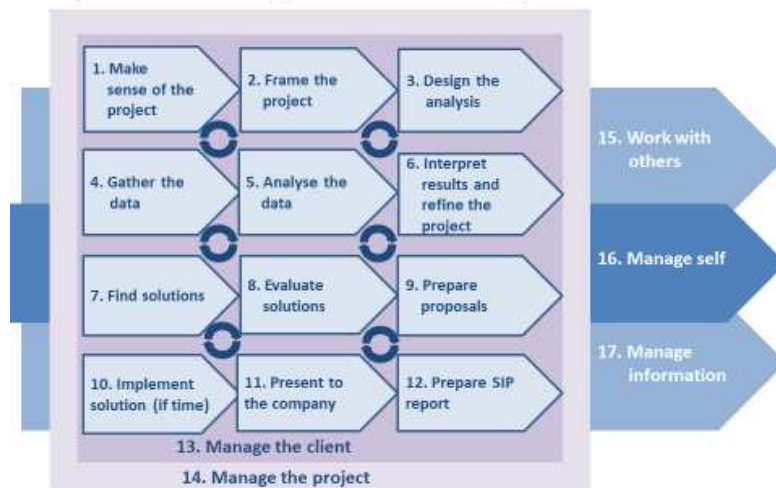


Figure 1: Seventeen task domains in a SIP

A variance research design was applied again and in three domains, 'manage the project', 'manage the client' and 'manage information', frameworks were generated from literature and compared with practice. For the other two domains 'work with others' and 'manage self' as no evidence based frameworks were found that related to the context of a placement then a grounded theory approach was adopted to answer the research question and inform theory development.

## KEY FINDINGS and DISCUSSION

Seventeen different task domains were identified as part of carrying out a SIP and twelve of these domains were 'process-stages' which were found to contain 64 indicative tasks.

The five through-SIP domains were different in nature. 'Manage the project', 'manage the client' and 'manage information' were found to be project delivery centric domains where as 'work with others' and 'manage self' were found to be people centric domains. This led to a reconfiguration of the 17 domain framework which is shown below in Figure 2.

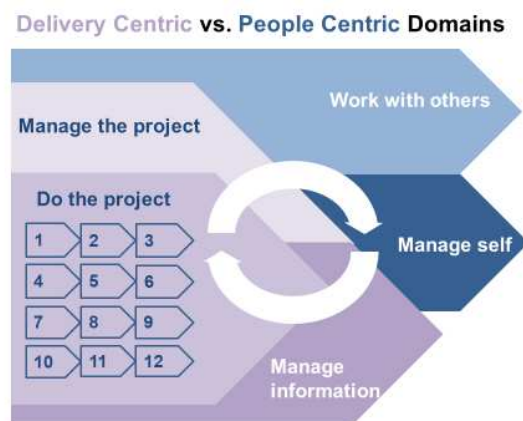


Figure 2: Reconfigured SIP Framework

The delivery centric domains overlapped with some 'process-stages' and also contained repetitive tasks such as 'review progress' and housekeeping tasks such as 'secure data'. 52 tasks were identified across these three domains and further refinement to their descriptions is required for improved alignment with the context of the two-week SIPs.

The two people centric domains, 'work with others' and 'manage self', were multi-strand domains. 'Work with others' was found to contain two main strands of 'communication' and 'working in a partnership' and 'Manage self' five strands of health, thinking, self, being professional and managing my work. Around 80 tasks have been identified in each strand and further work is required to investigate this in more depth. What is clear at this stage is that these 'through-SIP' domain tasks are far more extensive than previously described.

A further key finding is that students repeatedly identified 'behaviours' as challenging people-centric tasks; with sixteen behaviours captured in both domains. Being focussed and open-minded were the top two significant behaviours associated with 'manage-self' and being able to trust your partner was the dominant behaviour for 'work with others'.

The overlaps between the different domains and the nature of different tasks types remains to be fully resolved.

## CONCLUSIONS & RECOMMENDATIONS

Describing skills as tasks has been effective way to develop descriptions that support teaching and learning with tasks associated with processes being easier to capture than those related to people.

Through-SIP domains are more extensive than previously described and it is recommended that further work is undertaken to improve the description of tasks and extend the investigation of the people-centric domains.

The relationships between task domains are complex. Additional work is required to resolve issues with overlapping and repeating tasks.

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## Challenging Industries – An Enterprising Module Led By Industry.

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**KEYWORDS:** Enterprise, Industry, Engineering, Transferable skills, Partnership

### SUMMARY

Following consultation with our strategic industry partners, the Advanced Biomanufacturing Centre (ABC) was keen to ensure that students on the MSc Biological & Bioprocess Engineering course were able to evidence key transferable skills required for employment in industry posts.

Working with University of Sheffield Enterprise Academy (USE), the ABC designed a new 15 credit elective module which gives students the opportunity to work in small groups on an industry-set project. It includes an industry visit and several external speakers who cover topics such as creative thinking and business constraints which may not be typically covered in an engineering qualification.

Introduced in spring semester 2016, the programme is being delivered in partnership with Fujifilm Diosynth Biotechnologies (FDB) ([www.fujifilmdiosynth.com/about-us](http://www.fujifilmdiosynth.com/about-us)) and now attracts at least 85% of the total MSc cohort.

### BACKGROUND / CONTEXT

It has long been reported that engineering graduates leave higher education lacking the skills that enable them to apply their subject knowledge in enterprising ways to develop product or customer solutions. The IET reported in 2014 that such skills fell short of the expectation of employers when it came to practical and leadership experience<sup>(2)</sup>. The benefits of work placement experience are now well recognised, with the National Centre for Universities and Business reporting the benefits for the student, the institution and the business in its report in 2014<sup>(3)</sup>. Indeed, the Wilson review of business-university collaboration<sup>(4)</sup>, commissioned by HEFCE in 2012, made a series of recommendations to alleviate the barriers to employment that so many graduates face. This is now a well adopted model with many undergraduate degrees offering placement years or sandwich courses, and at the University of Sheffield, the Faculty of Engineering offers a Year in Industry opportunity in many of its subject disciplines.



However, for those students studying a one-year taught Master programme, there is no time available for such a model to be incorporated, and many of these students have studied a first degree where business collaboration was not available. This prompted the authors to develop an elective module to provide some industry interaction and offer the students the opportunity to practise and develop some of the enterprise and employability skills required by their future employers.

### **AIM AND OBJECTIVES / RESEARCH QUESTION(S)**

Working together, the ABC and USE developed a new elective module which enabled students to experience first-hand the challenges faced in biotech industries. The structure of the course is designed to develop the set of enterprise and employability skills that our industry partners have told us they require in their graduate workforce, delivered through USE's five stand model of enterprise education. Specifically, it develops students' skills in:

- Team working & negotiation
- Creative approaches to problem solving
- Communication and oral presentation
- Decision-making based on own judgement
- Building technical know-how and applying it
- Considering financial implications in business.

Key to the development of this module was the shared vision of both the ABC and its industry partner to develop engineers with transferrable skills as well as technical knowledge.

### **RATIONALE**

In order to design a module with the best fit for industry needs, we aligned the ideal candidate profile with the Enterprise Capabilities framework developed by the University of Sheffield Enterprise Academy and devised a 12-week, 15-credit module. This was matched to the set of competency criteria established by FDB, which are designed to encompass global job requirements based in Research & Development. The criteria aim to provide a consistent approach to performance management and personal development across various roles and departments within the company structure. They detail the expected level of competency across 'hard' and 'soft' skills. By working with the industry partner on the module design we were able to ensure that the learning outcomes required at MSc level were understood, and that the academic input provided relevant, demonstrable experience for its students to take into employment.

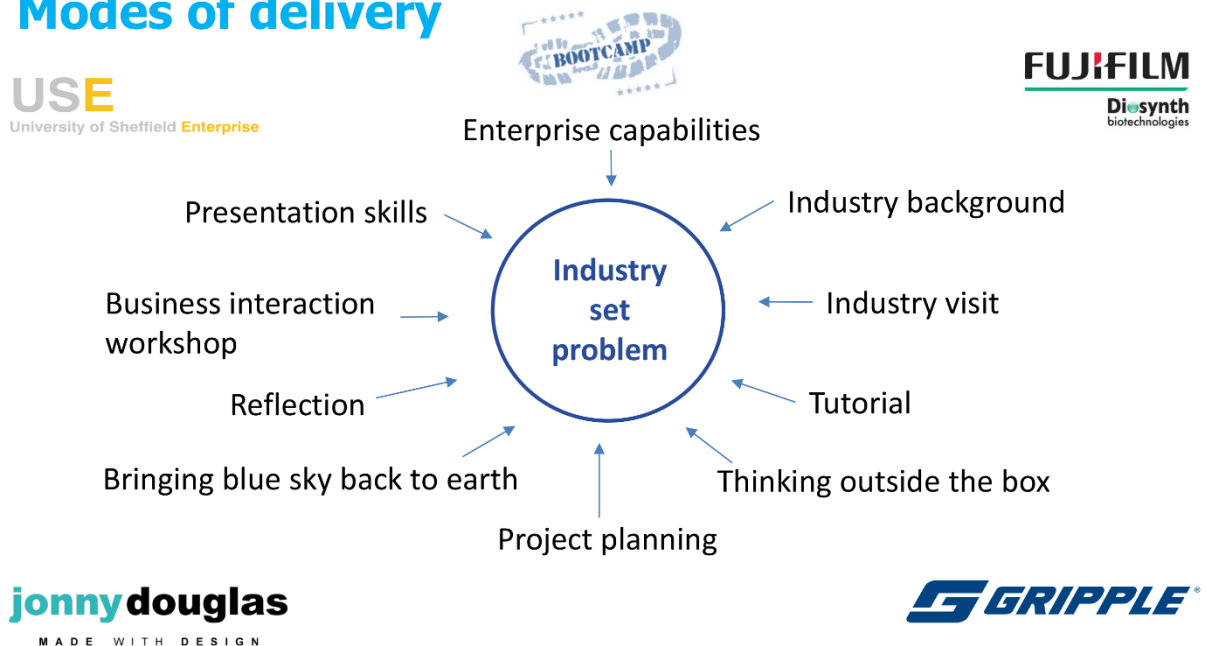
### **METHODOLOGICAL APPROACH**

The ABC visited several of its industry partners prior to establishing this module. Without exception they identified that the biggest barrier to employing postgraduates

was the students' ability to contextualise their learning. Whilst interviewees can discuss technical competency, evidencing good communication and teamwork, for example, within the work environment is more challenging.

Combining the feedback from industry with feedback from student focus groups, the ABC was able to work with USE to devise a new style of module where skills are introduced intensively at the start and then practised through an authentic industry problem solving exercise. Beginning with a 2 day interactive bootcamp, students take part in engaging activities that provide the tools to develop their skills over the 12-week semester. They have guest speakers throughout the module, covering topics such as creative thinking and preparing business presentations. The skills are applied and tested on a real problem which they are set at a visit to the biotech industry partner, Fujifilm Diosynth Biotechnologies. By the end of the module, students present solutions to this problem, thereby creating a real-world example of applying their skills in an industry context, for their portfolio. The novelty in this case is that enterprise skills development is not traditionally offered within science and engineering post-graduate courses, so the module gives our graduating students a better chance of employment on leaving the University of Sheffield.

## Modes of delivery



## KEY FINDINGS

The teaching style of this module is totally different from anything the students have experienced before. Our international students have largely been used to formal lectures with a high number of students and really appreciate the opportunity to get 'hands on' with practical learning. Comments have been overwhelmingly positive, and included, for example:

*'It teaches skills you cannot learn in normal classroom lectures'*

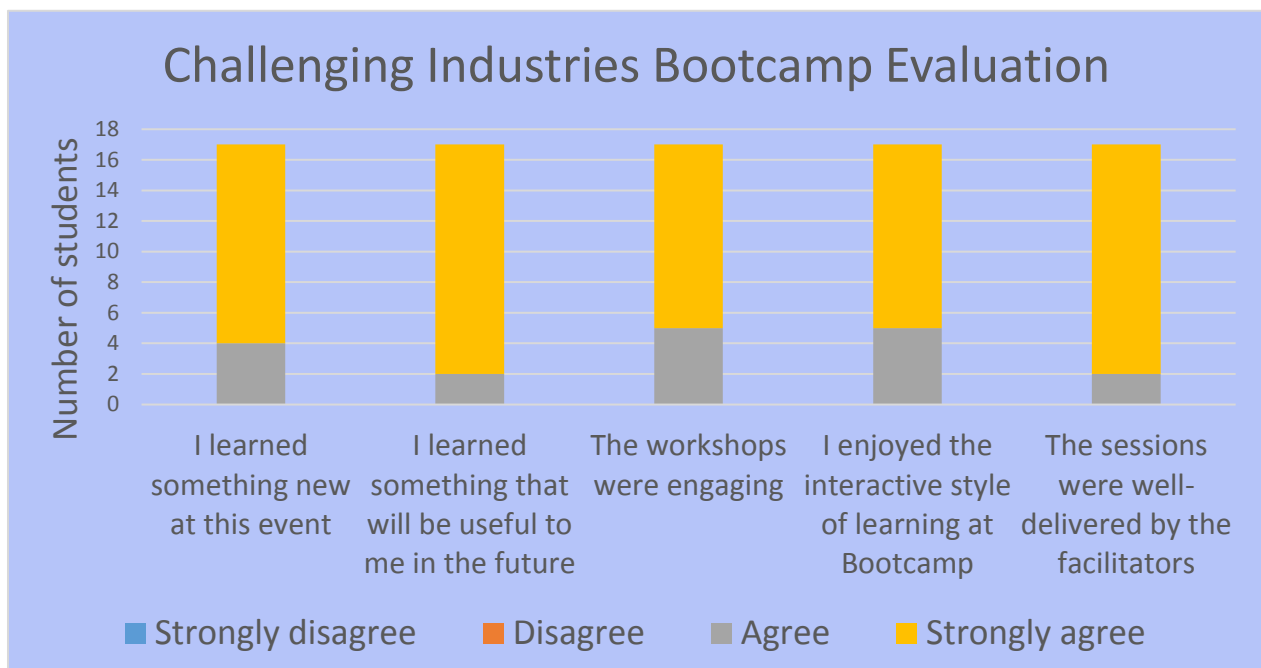


*'It helps us be on the right track in our efforts to apply own skills to knowledge'*

*'Gets people thinking outside the box. Helps adapt to the workplace'*

*'Teaches us knowledge from practise, not from a book, which is a really good method'.*

Feedback from the bootcamp showed that 100% of students learned something new that they felt they would use in the future, and that they were engaged and enjoyed the interactive learning style.



Feedback from our industry partner has been equally positive as it has given them a greater understanding of the departmental offer, access to work-ready graduates, collaborative opportunities and development potential.

## DISCUSSION

The module has been designed to provide the students with an authentic industry experience allowing them to test their problem-solving ability in the absence of a work placement. It provides the opportunity for students to put their knowledge to the test, whilst practising and developing the enterprise and employability skills we know that the industry requires. Feedback from the first two cohorts has been exceptional. The students are clearly developing their skills and FDB is glad to be part of a programme that can help educate the engineers that will be the next generation employees and leaders of bio-pharm.

It is potentially a win-win as the students learn more about a particular industry and links with potential employers, and industry partners, such as FDB, help us, as

educators, develop graduates and post-graduates with the skills they need. It may also have the potential to identify potential new recruits.

Many of the ABC's other industry partners have agreed to support the module by providing project input, visits and support and it appears to be a model which could be used in various undergraduate and postgraduate qualifications.

## **CONCLUSIONS & RECOMMENDATIONS**

Working closely with industry partners ensures we are educating our engineers with relevant, contextualised learning that may improve their progression throughout their development as leaders of the future. FDB have now supported us for 3 years and are happy to continue to do so as they are already seeing the benefits through access to high calibre students.

We were fortunate to have an industry advisory board to facilitate access to potential partners for this, and many were/are happy to contribute to curriculum development. Identifying a 'champion' within that organisation has ensured that it has been well supported, and a pipeline of willing industry engineers has emerged within FDB.

Departmental and Learning & Teaching support also allowed this new style of module to be piloted and aligned with the module marking scheme.

Key recommendations include:

- Making sure your industry partner has an interest in developing the education of engineers.
- Using the right people to make the right connections. This may not be an academic for this type of module.
- Ensuring partners can identify the 'win' for them.
- Nurturing the relationship and revisiting the delivery and topic each year.

We believe that a top university education is important, but those individuals who can set themselves apart by applying their knowledge and skills in the wider context are greatly sought after.

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# Understanding the Student Experience in One-Year Graduate Masters Programmes

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**KEY WORDS: Postgraduate taught, Research skills, Student support, Student community**

## **SUMMARY**

We present initial findings from a study investigating PGT student experience, aspirations, and perceptions of general skills required to undertake engineering research as part of their degree programme. A survey and focus groups were used to obtain data from two consecutive student cohorts across a Russell group engineering faculty.

The study found that students are less content with their communication skills than their discipline-specific research skills. They are pleased with their research supervisors, but do not feel part of a larger research community. Nor do they feel part of a larger university-centred student community.

We are extending this initial work through further surveys, focus groups and one-to-one interviews with students and their research supervisors to find ways to build a learning community within cohorts.

## **BACKGROUND / CONTEXT**

Much of the literature in the field of Engineering Higher Education focusses on undergraduate education and student experience, yet within the UK, in 2014 / 15, 19% of students were studying on postgraduate taught (PGT) programmes (HESA, 2016). Moreover, in terms of engineering education, UK PGT and undergraduate populations differ demographically (EngineeringUK, 2017). PGT engineering students are more likely to be female and from overseas. We hypothesise that research based on undergraduates may not be directly applicable to PGT, whose needs, aspirations and motivations for study are different.

## **AIM AND OBJECTIVES**

The preliminary study aimed to investigate the experience of PGT Engineering students, mostly following one-year full-time programmes, at a large Russell Group university. The institution aims to embed research-based teaching across its curricula, enabling students to feel part of a supportive scholarly community (Fung, 2017). This work considers students' perceptions of the support they feel they require and receive



in areas outside of the core taught material in their programmes – research skills and project support, and pastoral and social support.

## **RATIONALE**

This study has provided a baseline set of data that gives a view of the current status of student support and students' aspirations for their education. It is a first step in a process to evaluate PGT education within a single institution. Nevertheless the conclusions and recommendations are applicable to institutions with a similar demographic of PGT students.

The work has focussed on elements common across the university's engineering disciplines – research projects and skills, and generic student support.

## **METHODOLOGICAL APPROACH**

An online survey seeking both qualitative and quantitative responses was sent to over 1300 graduating (2015/16 cohort) PGT students from the Faculty of Engineering Sciences in September 2016. The survey contained questions about the students' research project loosely based around those in PTES, with additional questions to assess whether students felt part of a research community and also which research skills the students would have liked more support to develop.

The survey was followed by three student-led focus group sessions in March 2017. The 25 focus group attendees were taken from the 2016/17 cohort. A group of four PGT students were trained in running focus groups and they then carried these out without a staff member present to reassure those taking part that their responses would remain anonymous. The focus groups were 44% female, 56% male; 20% UK, 20% EU and 60% overseas.

## **KEY EMERGENT FINDINGS**

This work in progress is part of a study tracking PGT student expectations, aspirations, and perceptions of support over multiple years. These initial findings are our first data and show:

- 82% agree or strongly agree that 'My supervisor has the skills and subject knowledge to adequately support my dissertation/project'
- 74% that 'My supervisor provided helpful feedback on my progress'
- 40% that 'I was given the opportunity to discuss or present my work to my peers and others in the department'
- 43% that 'I felt part of a research community during my project/dissertation'.

The students feel that they need particular support in academic writing and preparing their final report, data analysis, and project management.

Themes from the focus groups were:



- i Students would like more support with presentation skills;
- ii Many students are studying to improve their employment opportunities, and they are very conscious of this throughout their studies;
- iii They would like the opportunity to become part of a community through networking opportunities and student societies that will lead to them considering the university as their 'alma mater';
- iv Their expectations of facilities prior to arrival were not fully met when they embarked on their programmes of study.

## **DISCUSSION**

The initial results from the survey indicate that although the students carry out a significant research project and feel supported by their supervisors in doing so, they do not feel part of a larger research community. They may be operating in a research relationship more closely akin to that of a sole student learning at the feet of a master and thus missing the benefits of being part of a learning community (Zhao & Kuh, 2004). The survey also highlights that the students, although feeling supported in their discipline specific research, feel that they could be more supported in translational skills such as presentation and academic writing. These skills will apply across all engineering education and are becoming increasingly necessary for the future employment of our graduates (Perkins, 2013).

The concept of community arose again in the focus groups, with the emphasis on the students wanting to be part of an alma mater network. The intense but short nature of Masters programmes could be the driving reason for this and we suggest that a sense of community could be built by improving communication throughout the entire student lifecycle from pre-application to post-graduation.

## **CONCLUSIONS & RECOMMENDATIONS**

This initial study has shown that PGT Engineering students in a Russell group institution would like more support in general skills associated with engineering research, and also do not feel part of a research community despite one third of their programme being a significant research project.

We will continue this study with surveys to track cohorts supplemented by focus groups and one-to-one interviews with students and their research project supervisors to investigate their confidence and ability in generic research skills and their personal learning gain throughout the experience.

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# Comparison of Transversal Competence Levels of Engineering Students With Labour Market Requirements

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**KEYWORDS:** Transversal competences, competences mismatch, Engineering Education Research, measurement tool, curriculum elements

## **SUMMARY**

The globalization and the great change in technology of the 1990's brought a particular importance in developing transversal competences (Shuman, 2005). ERI-Net defined transversal competences as "skills, values and attitudes that are required for learners' holistic development and for learners to become capable of adapting to change" (Care 2016), for instance communication skills, teamwork, and innovative thinking.

Although there is high degree of agreement on the importance of the transversal competences, employers observe a significant discrepancy between the preparation of graduate students and the academic work and the labour market.

In this study, some curriculum elements are proposed to integrate the curriculum of aerospace engineering (AE) Master students at Delft University of Technology (TU Delft) and a measurement tool is developed to measure the competence level of engineering students.

## **BACKGROUND / CONTEXT**

Some curriculum changes have been implemented to prepare students for future careers, these include: hands-on design projects, experimentation lab, internships in industry (Kamp and Verdegaal, 2015), guest lectures, company visits, etc. Although many institutions eagerly implement transversal competences in their curricula with an aim to better prepare students for the labour market, current literature remains sparse with little evidence of robust and effective measures to assess the development or improvement of transversal competences in engineering curricula. Often, a simple self-assessment of participants is the only form of evaluation; moreover, there appear to be no longitudinal studies where students were followed in the years after graduation.

## OBJECTIVES & RESEARCH QUESTIONS

The objectives of the study are twofold:

- 1) Integrate curriculum elements which focus on the acquisition of communication and lifelong learning competences into an existing course at AE Master degree in TU Delft.
- 2) Select and build a detailed definition and measurement tool with five transversal competences needed to reduce the gap between the labour market requirements and engineering graduates' competences. This measurement tool will be used to measure the competence level of AE students in the beginning and in the end of the course and to find out the required competence level that students should hold at graduation from industry perspective.

This study is driven by the following research questions:

- 1) What transversal competences are needed to reduce the gap between the labour market requirements and engineering graduates' competences?
- 2) What is the level of improvement of AE Master students for each transversal competences after course implementation?

## RATIONALE

This study attempts to measure a set of transversal competences on scales with rubric descriptions rather than Likert scales. Therefore, a detailed rubric instrument with four described levels will be used to assess transversal competences of engineering students before and after a course, and to predict the student competence level at graduation from industry perspective. In addition, curriculum elements focusing on communication and lifelong learning will be introduced into the existing Master program of AE.

## METHODOLOGICAL APPROACH

A detailed definition of five transversal competences (entrepreneurial competences, innovation competences, communication and networking competences, teamwork and thinking competences, and lifelong learning competences) important for engineering graduates is proposed based on previous literature (Shuman et al., 2005; Adeyemo, 2009; Passow, 2012; Benjamin et al., 2013; Chan et al., 2017) and an industry competence model (Siemens, 2010). These competences will be validated from experts working within the aerospace industry and other engineering industries, and working in engineering universities, through a questionnaire. Furthermore, in this questionnaire a rubric with the selected and defined transversal competences will be used to measure the competence level of engineering students before and after a course of the AE degree in TU Delft.

Curriculum elements focusing on visual, listening and questioning communication, and reflections will be integrated in the curriculum of AE to improve or develop communication and lifelong learning competences.

## EMERGENT FINDINGS

The validation of the measurement tool from industry experts is expected until the end of 2017 and the curriculum elements will be implemented from February to April of 2018.

## DISCUSSION

The use of a scale with detailed level description will provide information about the level that a graduate should hold at graduation according to industry experts and the influence of the implemented curriculum elements on student competence acquisition. The findings will inform students about the competences they must have at graduation to be successful in the labour market, and university about the impact of the introduced curriculum elements.

## CONCLUSIONS & RECOMMENDATIONS

In a fast, changeable and digital world, the cooperation between industry and academia is essential to prepare the students to a successful employment. This study attempts to involve industry and academia by asking them the required levels needed at graduation through a scale with a described level rubric, and by integrating elements which may improve transversal competences needed at graduation.

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## A New Curriculum to Train Chemical Engineers to Solve 21<sup>st</sup> Century Grand Challenges

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**KEYWORDS:** Capstone Design, Morphogenesis, Structural Change, Vertical / Horizontal integration, Curriculum Design

### SUMMARY

The Department of Chemical and Biological Engineering at the University of Sheffield is embarked on a curriculum change project with roll out starting with level 1 in September 2017. The drivers behind the change included the need to modernise the curriculum both in terms of content, structure and delivery. The main objective was to develop a modern Sheffield Chemical Engineer. The study is primarily about investigating the efficacy of the change efforts that have been introduced, to track progress and to determine whether we are meeting our stated objectives. The objectives are in relation to student success, student experience, curriculum coherence and student and staff well-being. Specifically, the new curriculum will be coherent, embedded in design and practice with an emphasis on critical thinking, problem solving, professionalism, ethics and sustainability. It will offer flexible learning environments and pathways to facilitate deep engagement. It will promote and facilitate industry involvement by focusing on both process and product engineering to develop industry ready practical graduates with hands on experience. It will produce graduates who are integrators, change agents and self-directed learners to lead multidisciplinary teams, and be at the forefront of innovation. It will provide exposure to niche research areas built on a strong core in engineering fundamentals. Lastly, it will produce graduates capable of Engineering from molecules by applying systems level thinking at many length scales. We have identified a third year module process design as a significant check point to determine whether some of our curriculum objectives are being met (Patwardhan et al, 2017).

### BACKGROUND / CONTEXT

The department has experienced a number of significant changes over the last couple of years in terms of academic staff. These changes brought fresh eyes and fresh enthusiasm which facilitated a close look at 'how we do business'. The curriculum redesign project was borne out of a need to redefine how we do engineering education, arguably our core business. We needed to think about the sorts of graduates we are looking to develop, the kind of programme we need to design to meet this objective (including programme outcomes), the kind of people to structure it and to action the changes.

## AIM AND OBJECTIVES / RESEARCH QUESTION(S)

The research questions are:

- *What are the hallmarks of a modern Sheffield Chemical Engineer?*
- *What curriculum structure and content will facilitate the development of the modern Sheffield Chemical Engineer?*
- *What pedagogies will enhance the student experience and staff enjoyment and why?*
- *What are the appropriate program evaluation measures or proxies and why?*

The primary aim of the research is to develop a new curriculum to meet specific objectives as stated above. A further aim of the research is to document good practice with respect to structural change projects while remaining constructively critical of our processes.

## RATIONALE

In an era of fee-paying students, we hear often, 'I have paid £9000 to be here, therefore ....'. Whether one considers this to be a substantive driver for change or not, it is undeniable that we need to provide a service to cohorts who are increasingly viewing themselves as consumers of our service. We operate in an era of tough competition for such students and need to raise our game and be competitive. This requires that we carefully (re)craft our identity to reconsider how we teach, what we teach and who we are teaching for. This also requires that we think carefully about why school leavers with a myriad of options should come to us for a unique engineering education experience and how we aim to make sure when they leave they hit the ground running wherever they end up.

## METHODOLOGICAL APPROACH

The research design follows the logic presented in the idea of structural morphogenesis (Archer, 1995).

We identify specific structural and pedagogical deficiencies in terms of our curriculum. We know these exist because we have performance measures in relation to our students; we have module and programme outcomes, and assessment processes. We also have various program evaluation measures in place. We then introduce a change that rolls out over a certain time; from T0 to time T1. The change has specific objectives related to the identified deficiencies as well as broader aspirational ones. After time T1, we evaluate our progress to see whether the objectives have been met, i.e. we are looking for morphogenesis. A perfectly valid finding could be that we are in fact achieving stasis, i.e. no changes at all or very limited changes, or that we have unintended consequences and outcomes. We have identified the capstone module

process design taken by third year students as one of a number of key vehicles to ascertain our progress in delivering the new curriculum. Design is an integrating principle; by its nature process design can give valuable information about what students know and can do, versus what they should know and do by the time they get to third year. Design is therefore an important check point.

Theories at work here are structural change theories (Archer, 1995), theories of knowledge which tell us something about the nature of engineering knowledge which is necessary to build a curriculum (Bernstein, 1999), as well as theories that speak to pedagogic practice and student learning (Sadovnik, 1991).

The data collection instruments include, module surveys, program surveys, program documentation. Focus groups and interviews will be used as necessary. The analysis will include statistical analysis as well as thematic analysis.

## **KEY FINDINGS**

This is a work in progress as the new curriculum only started in September 2017 with level 1 students. We have various data all of which represents data at point T0. This was derived from a survey of current self-selecting third years. These students identified deficiencies in aspects of our current program offerings namely computing, problem solving, relevance of some content, content sequencing, practical work in relation to theory, and design. Moreover, it was clear from these comments that we need to do better in vertical and horizontal integration. We also have specific information in relation to some of our current modules some of which will either be terminated, refocused or rebranded in the new curriculum. The decision as to whether to terminate or refocus etc. is based on our own assessment of what we would like our curriculum to be and to offer, based on in-house expertise, as well as industry members who are a core part of our engineering education team.

## **DISCUSSION**

Most if not all engineering education departments aspire to be research-led in their teaching. Most aspire also to be relevant in terms of industry expectations of graduates. These imperatives are not always complementary and it is the challenge of any engineering department to reconcile these imperatives. Students want to know that what they do matters, that there is a point to it and that they can use it in industry. One student notes that she changed from the MEng to the BEng with a year in industry because, "the thought of doing a research project to me sounds like my worst nightmare! As strange as it sounds, I've never been the academic type- always enjoyed more hands on practical things." This student is a first class student currently doing her year in industry. On the other hand we have students who relish the thought of a theoretical research project with no immediate relevance in industry. We need to be creating educational experiences and environments where both sets of students are validated and accommodated, which is not always going to be easy.

## CONCLUSIONS & RECOMMENDATIONS

Engineering education departments have much more to contend with in the modern age of the instrumentalist view of knowledge and education. This creates a specific challenge for some modules, those understood by us to be fundamental to engineering education, and perceived to be theoretical. The challenge is both that of knowledge representation and delivery, the what and the how, but one of collegiality as well. In delivering these modules and these modern programmes, we have to be mindful about creating silos and empires, impenetrable knowledge boundaries where we keep out not only our colleagues but also our students. This challenge is one that we will surely have to fight against as we develop our curriculum in an effort to develop Sheffield engineers that generate solutions for 21st Century grand challenges in energy, climate change and human health; that are open and outward focused, comfortable working in or leading culturally diverse and interdisciplinary teams; that are excited to attack complex and wicked problems; that are innovative product developers, forward looking, risk taking, trail blazing and finally that are proud of the manufacturing heritage of their university and city (Patwardhan et al, 2017).

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## Introducing Human Factors within a CDIO 1<sup>st</sup> Year Module: Has it Made a Difference to Appreciating the Vehicle Design Process?

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**KEY WORDS: Human Factors, Anthropometry, Percentiles, Vehicle Design, Package Drawings**

### ABSTRACT

The study describes the process of introducing anthropometry within term 1 of a first year CDIO module based on the GreenPower Formula 24+ racing competition. An appreciation of human requirements was intended to facilitate the assignment to 'Conceive, Design, Implement and Operate' (i.e. the four elements of the CDIO learning framework) an electric racing vehicle capable of safely transporting a driver around a hard-surfaced undulating track of between 300 – 600m. The 145 students (14 females and 131 males), including 35 designers, were randomly allocated to 12 groups containing 12/13 members, each group contained between 1-4 designers. Female students comprised between 8% and 25% out of each of group, however there were 6 groups comprised of solely male students.

### BACKGROUND / CONTEXT

The CDIO (Conceive, Design, Implement, Operate) initiative was developed in order to provide engineering students with the opportunity to practice skills such as design, teamwork and communication (Crawley 2007). It advocates employing active learning techniques in order to significantly increase students' learning. The CDIO approach to engineering education is based on experiential learning theory, as proposed by Kolb (1984).

Students were introduced to human factors in week 3 of the module via a series of lectures followed by meaningful learning activities (Prince 2004) designed to illustrate how their vehicle chassis design would fit the user(s) with reference to anthropometry, 2D scale manikins representing user percentiles, package drawings and 3D scale models. These outcomes are representative of human factors issues considered within the automotive industry (Happian-Smith 2002).

Assessments of this 12 week CDIO module consisted of 4 formative 'design review' gateways and 4 different summative submissions - 2 individual, namely a logbook and

an individual report submitted in the final weeks. These submissions would be assessed using marking matrices. Individual reports were to contain reflections highlighting students' personal learning achieved by undertaking the project.

## **AIM AND OBJECTIVES**

The aim of the study was to find out how engineering and design students incorporated human factors requirements by reviewing their personal reflections as described in their individual reports required for the design and build of an electric racing vehicle.

The objectives of the study were to gauge how:

- Active learning approaches were used for human factors;
- Human factors subject matter was integrated within the vehicle project;
- Students embraced learning and applying human factors.

## **RATIONALE**

The study set out to shed light on how engineers and designers interpret and depict human factors data associated within this CDIO module covering vehicle design.

Incorporating human factors is an important issue since previous research by Broberg (2007) suggests that practicing engineers value integrating ergonomics into engineering but this is not necessarily supported in engineering education. Moreover, Skepper et al (2000) concluded that basic ergonomic issues need to be better understood by designers and engineers in order to address their assumptions about the use of anthropometric data and acknowledging the involvement of the user in the design process.

## **METHODOLOGICAL APPROACH**

Utilising qualitative research techniques, a content analysis of student reports was undertaken. The report assessment matrix was used to establish the contents of the report. This method was selected as it allowed for an examination of the 'concept and design' and 'build' stages of the project. The methodology also enabled an in-depth examination of students' conclusions and reflections which were aimed at highlighting personal learning achieved by undertaking the project.

## KEY FINDINGS

Key findings revealed that there was generally a very low acknowledgement of human factors within the reports in terms of commenting upon the activities that the students had engaged in and/or been supplied with information to further explore human factors issues.

The majority of comments about human factors came from engineers compared with responses from designers. There also appeared to be some confusion over students reporting from their group activities in terms of which percentiles should be considered for driver selection shown in package drawings.

There was also a relatively small number of students who showed either their groups package drawings in their reports and/or photographs of 3D 1:5 scale manikins positioned in their 1:5 scale chassis model prototypes.

### - **Active Learning Approaches**

The active learning approaches mainly focused on activities introduced within the classroom which consisted of instructional content for:

- A measuring exercise to determine group members measurements and percentiles;
- Making 1:5<sup>th</sup> scale 2D manikins to represent largest and smallest global percentiles and the designated driver of each group, to test in 1:5<sup>th</sup> scale package drawings.

Not all active learning instructional exercises were reflected upon in the reports. Specifically one of the first exercises involved students measuring each other for 12 different 'static' dimensions. These dimensions were to be translated into percentiles using PeopleSize 2008 (visual anthropometry software). Only 7 students specifically commented on the measuring workshop itself in terms of where dimensions for their driver would originate; towards three quarters of the responses came from engineers. The responses were from students belonging to half of all the groups; with 2 responses originating from the membership of one group. The 2 designers that made reference to the measuring workshop were in different groups made up of entirely male students.

### - **Human Factors Data**

A total of 18 engineers and 5 designers made reference to the size of the driver as depicted by 2D manikins.

It appears that most groups had different approaches for developing the 2D manikins to be used in package drawings. Some teams produced both the largest 97.5<sup>th</sup>%ile US male and smallest 2.5<sup>th</sup>%ile Chinese female manikins and represented these in package drawings, but some groups appeared confused about the nationality that the data represented.

It was also noted that there seemed to be different approaches for selecting a driver amongst the groups. Some group selected their driver without providing any reasoning whereas other groups selected their driver based on their measurements being:

- Closest to the smaller (less than 50%) dimensions
- Closest to the 50<sup>th</sup>%ile dimensions
- Closest to the largest male uk percentiles
- Closest to the average of every group member's percentiles

Representative comments include:

*"The dimensions of the chassis were based on the chosen driver. Our chosen driver was on the smaller side"*

*"XXX was chosen as the team test driver, due to most of his anthropometric data being close to the 50%ile population mark"*

*" All of the dimensions of the chassis will depend on 97.5 percentile anthropometry of the group"*

*"Once each member had all their percentile values they could find the average of the team in order to create a manikin"*

#### **- Learning Human Factors**

Only a handful of the students made reference to human factors in their reflective accounts. Their reflections were based more on new skills gained rather than a breakthrough in their understanding of human factors issues in the design of a vehicle. Individual responses ranged from:

*"Now being able to understand and draw engineering drawings and packing people from an ergonomic perspective it was proven to be vital knowledge that would be most beneficial for the whole of my engineering career."*

*"The use and understanding of general automotive design, ergonomics and human factors proved to be invaluable to the team as the demands of the project required the team to produce package drawings, illustrate the anthropometry of the driver."*

Where students did make a reference to these skills these students had often gained one of the highest marks in their group.

No students stated the percentiles associated with their designated team drivers. Instead the selection process remained associated with measuring dimensions rather than converting into percentiles as described by comments like:

*"...the team had to measure all members, measuring for example horizontal fingertip reach and sitting height as well as others....help determine who should drive the car, or how long or short the chassis had to be for the driver "*

*"...one of the first workshop sessions was all about measuring our own dimensions....selected drivers would have to be measured carefully as their dimensions cannot be extrapolated from a few simple measurements"*

Only one student stated the dimensions of the group's designated driver but without reference to percentile data.

There appeared to be no significant difference between males and females in the way that the impact of human factors was discussed within the conclusions and reflections sections of the reports.

## **DISCUSSION**

The study contributes to Engineering Education as there is a recognised need to produce engineering graduates that have a wider understanding of the characteristics of the society in which they will operate (Rugarcia et al, 2000, Karwowski, 2005).

Whilst overall results were disappointing in terms of students' reference to human factors, it remains that this was the first year where human factors was introduced as a distinct taught element with the first CDIO module of the year. Relatively poor reflection of ergonomic elements compared with other taught content could also be explained by the fact that the majority of students were engineers rather than budding car designers with competent drawing skills. Therefore, the confidence associated with displaying sketched concepts or package drawings in the reports was often lacking.

Findings from this study therefore suggest that engineering students and designers need further support with their understanding and visual depiction of anthropometry and associated human factors. Aspects especially associated with translating human proportions into measurable data representing a consideration of smallest and largest drivers' anthropometric experiences as well as representing the human form in three dimensions.

## **CONCLUSIONS & RECOMMENDATIONS**

Whilst many students made general references to human factors, there appeared an inconsistency in appreciating its significance stemming right from the generation of the concept design stage through to development of the concepts in package drawings depicting 2D manikins of largest male, smallest female and chosen driver dimensions and interpreting this information into 3 dimensions. One recommendation therefore might be to make clearer the stages in which human factors can be applied within the CDIO stages. Indeed, these stages are part of the marking rubric categories which suggests that the production of diagrams and figures should be extended to specifically mention 'sketches' or depictions of 'package drawings' or 'photographs' of the build process including the 3D 1:5<sup>th</sup> scale model located in the driving position and demonstrating access and egress within the scaled chassis prototype.

There also appeared some confusion about how percentile information translated into the production of 2D 1:5<sup>th</sup> scale manikins and specifically the selection and representation of the driver's dimensions. To address this outcome, it therefore would be useful for groups to undertake a comparison of all the dimensions of their group members in terms of understanding which dimensions are critical for specific tasks i.e. horizontal fingertip reach (required to reach the steering wheel) based on minimum dimension of group member.

Whilst there are 4 formative 'design review' gateways there is currently no mechanism for students to learn from other groups practice. Therefore one of the ways of sharing good ergonomics practice might be for each group to present their formative knowledge to the larger cohort. Not necessarily in a one way presentation format but perhaps in a reflective and evaluative way explaining the trade-offs that the group has decided between structural design and accommodating human requirements.

Only 4 groups provided visual photographic evidence of them having translated their driver's dimensions into a 3D 1:5<sup>th</sup> scale models to test their 1:5<sup>th</sup> scale chassis design. Therefore this suggests that guidelines would be useful for making 3D versions of a driver.

Many groups also divided up the task of anthropometrics/package drawing between one or two group members. This approach could suggest that only a limited percentage of the group members ever got to really appreciate the trade-offs between accommodating the human and mechanical components of a vehicle. To address this issue all students at the beginning of design concepts generation could be given templates of a generic driver from a side elevation view, in different driving postures (such as sitting upright or at an angle or with knees bent etc). These driving postures could be used to evaluate and develop rough sketches at the start of generating side elevations required in package drawings to transfer details into other orthogonal views. In this way students might explore the proportions of their designs more systematically perhaps evaluating the effect of experimenting with the length of the wheelbase or where any of the side members be positioned in relation to the driver's posture.

## **CONCLUSION**

In conclusion, some of these recommendations are already being developed and subsequently incorporated into the same CDIO module running for the 2<sup>nd</sup> academic year. Initial observations are indicating that by addressing the issues above this is contributing in a positive way to the further understanding and visual depiction of human factors by engineering and product design students.

At the moment the week where ergonomics is introduced is largely based on introducing and applying anthropometric data. Going forward, perhaps this investigation might also be extended by incorporating some explanations of postures and associated strengths to take into account in the design considerations of adjustable features within the vehicles.

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## **Deliberate Practice Makes Perfect! Developing Logbook Keeping as a Professional Skill through CDIO**

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**KEY WORDS: Deliberate Practice, CDIO, Logbooks, Professional Skills**

### **SUMMARY**

Deliberate practice, including focused practice time by students, feedback from experts, mentors, educators or peers, and student reflection<sup>[1]</sup> is needed in order to develop and excel in any skill. This study looks at whether deliberate and directed practice can be used to develop professional engineering skills in a CDIO teaching setting, using logbook keeping as a key example.

### **BACKGROUND / CONTEXT**

Adopting the CDIO framework (Conceive-Design-Implement-Operate)<sup>[2]</sup> at Aston has facilitated better development of students' professional skills whilst bringing practical application to technical theory in team-based projects. However, studies have shown that practice alone has little correlation to improving performance and skills competence, whereas deliberate practice (practice with "deliberate efforts" to improve performance) has been shown to be effective in both<sup>[3]</sup>

At Aston, four major 12-week-long projects are delivered over the first two years of study on the mechanical engineering degree programs. With each project addressing different learning objectives, all share common threads in the application and development of professional and technical skills, such as logbook keeping, team working and problem solving. It is expected that with this regular repetition and formative feedback, students are engaging in deliberate practice.

### **AIM AND OBJECTIVES / RESEARCH QUESTION(S)**

The aim of this study was to identify whether the assessed logbook exercises from the four project modules effectively engage the students in deliberate practice and therefore develop this professional skill.

### **RATIONALE**

The research question is

*"Does the logbook practice and feedback throughout the degree result in*



*skills retention in logbook use during the final year project, despite there being no associated logbook assessment in the final year (FY)?”*

This evaluation will help elucidate the efficacy of current teaching practices that aim to instil core professional skills through the CDIO framework.

## **METHODOLOGICAL APPROACH**

### *- Questionnaires*

A questionnaire was delivered to students at the end of their FY projects at the time of dissertation submission. The aim was to gauge the students' retrospective self-awareness regarding project planning, logbook use, and skills confidence. The questionnaire design has been discussed in a previous paper[4].

The responses to logbook use in a previous study were used as a multiple choice question where students identified their logbook use according to the provided list using a 5-point Likert scale[4].

### *- Logbook Assessments Analysis*

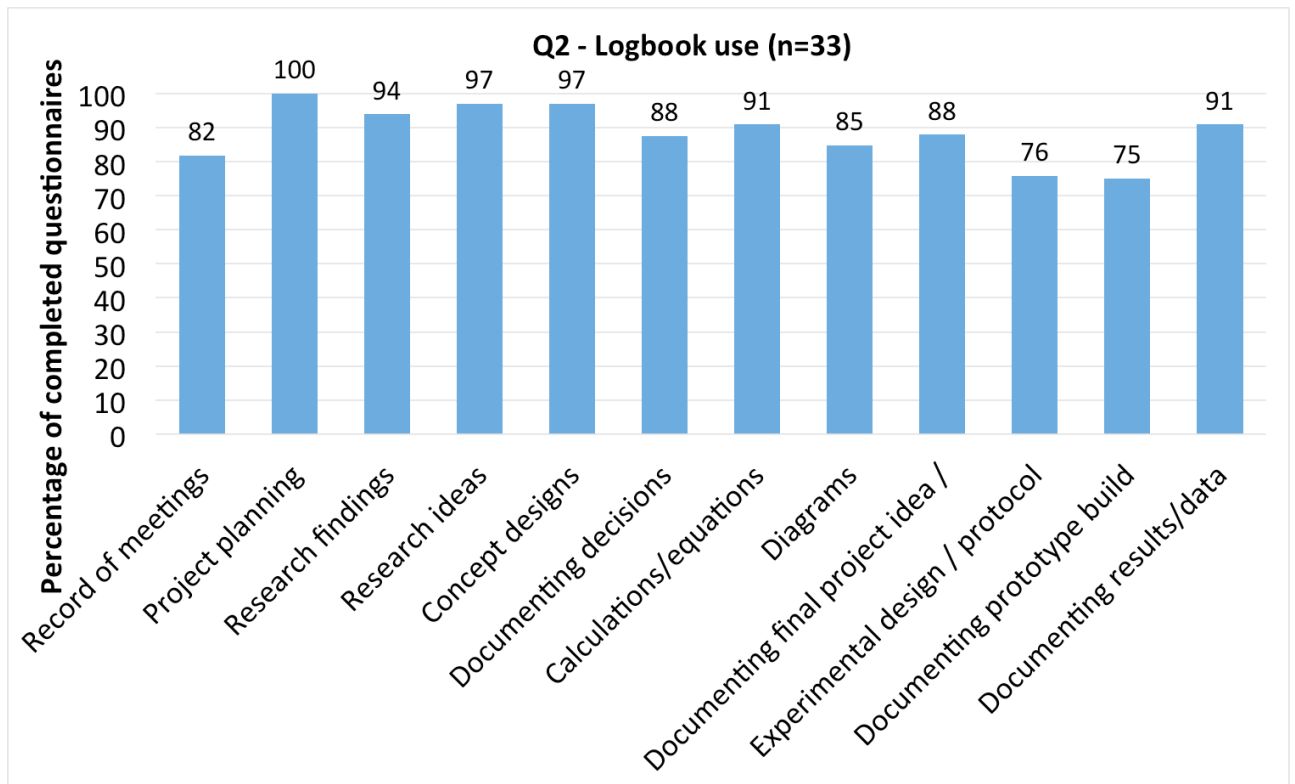
A longitudinal analysis of all FY students was carried out, analyzing logbook assessments over year 1 and 2. Logbook performance and changes in performance were analyzed for trends. An ANOVA test was carried out to test for significance between assessments.

## **KEY FINDINGS**

### **Responses for Logbook Use**

The questionnaire was completed by 36 students (43% of cohort). All students used their logbooks for project planning (100%) and lowest uses were for documenting the build (75%) and experimental design/protocol (76%) (Figure 1).

**Figure 1: Logbook use at end of project (Q2) showing 75-100% use.**



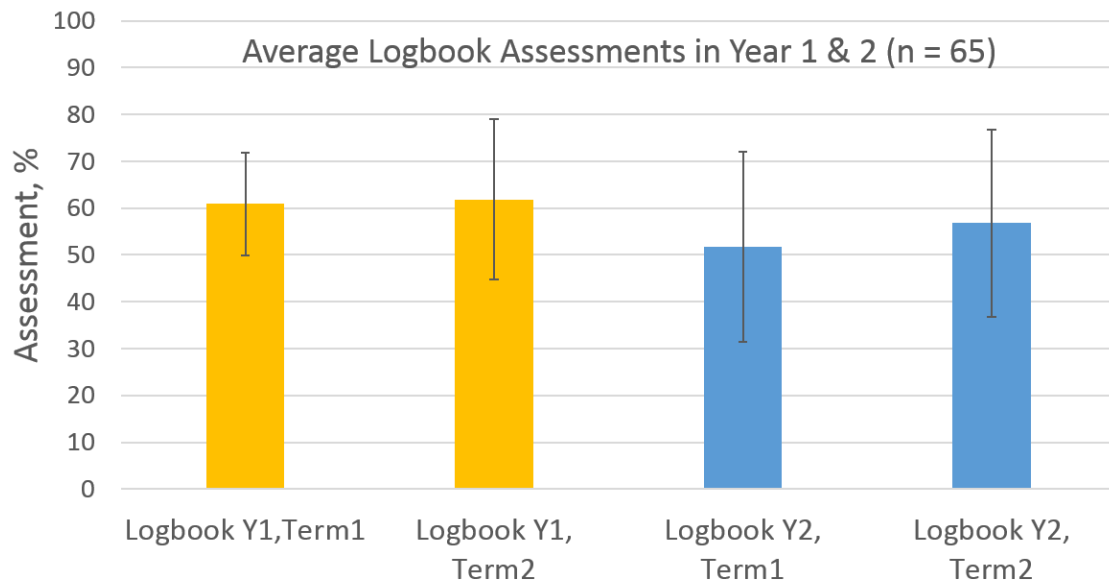
### Logbook Assessments Analysis

From the cohort of 83 engineering students, only students who had completed all required modules and been approved by the school exam board at the time of analysis were used for the study (n=65).

### Year 1 and 2 Logbook Marks

Average year 1 logbook assessments showed only a marginal increase in performance between term 1 and 2 (Figure 2). However, a drop in performance at the start of year 2, was observed, and an improvement in year 2 second term showed a significant improvement ( $p=0.05$ ).

**Figure 2: Average logbook performance in year 1 (yellow) and year 2 (blue) showed a significant drop in year 2, term 1, which was improved in term 2 ( $p = 0.05$ ).**

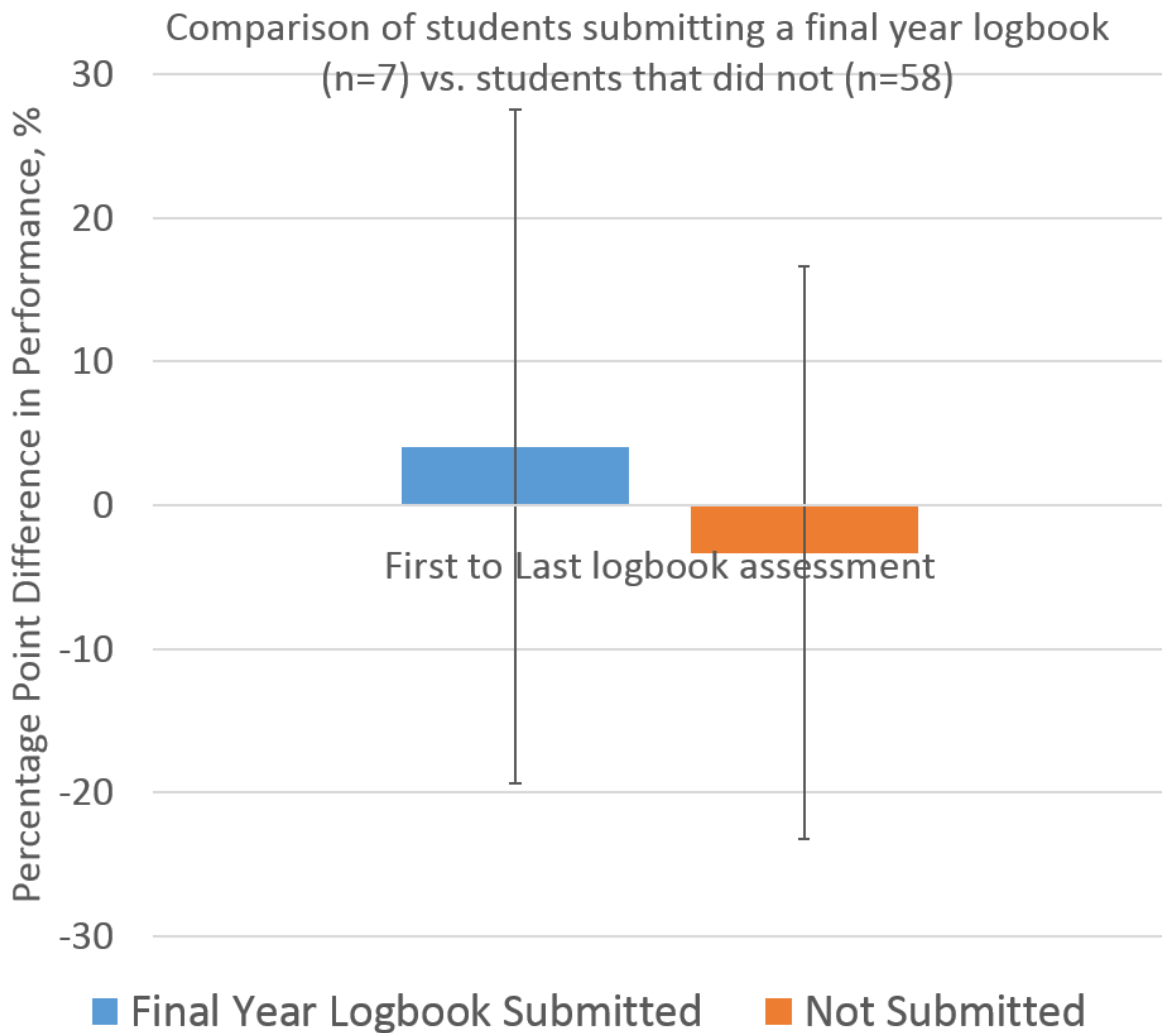


### Final Year Logbooks

Only seven out of 83 students submitted their FY logbooks for the purpose of this study (8%). Logbook assessment for these 7 logbooks had an average result of  $55.5 \pm 10.3\%$ .

When comparing the difference in performance from the first logbook assessment (year 1, term 1) to their last logbook assessments (year 2, term 2), the students who had submitted a FY logbook had improved their performance overall by  $4.1 \pm 23.5\%$  points compared to a drop of  $-3.3 \pm 19.9\%$  for those who did not submit (Figure 3, overleaf).

**Figure 3: Students who submitted a FY logbook showed overall logbook improvements over year 1 and 2 compared to those that did not.**



## DISCUSSION

The analysis for this study shows high retention of logbook keeping in FY projects with 100% of students in the study using their logbook for project planning. The lowest use of logbook was documenting prototype build (75%) and experimental design/protocol (76%), which may be due to some projects being theory-based. When reviewing performance, the longitudinal data of logbook performance over year 1 and 2 showed a pattern of improvement in each year but no positive trend over the 2 years. In fact the significant drop in performance between year 1 and 2 reflects the lack of practice between the end of first year term 2 and start of the second year term due to the vacation period (approximately 6 months). This may well be the primary missing element in implementing deliberate practice<sup>[1]</sup>.

The deliberate practice exercise does appear to be successful in continuing note keeping, as students continued in their FY projects. However, it does not appear to be successful in following good practice and maintaining good performance (though this is based on a small number of submissions). Although only speculative, it does appear some students are not practicing with a deliberate effort to improve.

## CONCLUSIONS & RECOMMENDATIONS

Deliberate practice to maintain logbook keeping was successful, however, improvement in logbook performance was modest and was highly influenced by other factors that warrants further study. Such factors as personal interest, student engagement, use of peer learning and extended periods of no practice. To develop professional skills, it is recommended to not only introduce repeated practice over a long period of time, but to also engage students in focussing on areas of improvement and engaging with the formative feedback. An intervention targeting the lack of practice over the vacation also warrants further investigation since this study shows the detrimental effect of no practice over several months.

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# SECTION 2A: VOICES FROM THE 'CLASSROOM AND LAB'

In an attempt to encourage colleagues with little or no pedagogical research background the Network Governance Board took the decision to accept papers which would not ordinarily be classified as 'Engineering Education Research' in terms of usual academic protocols. This open approach proved successful, encouraging colleagues who had previously not engaged with the EERN community to submit papers, attend the Symposium and interact with active researchers.

The following papers reflect this part of the Engineering Education community and reveal that innovation in learning and teaching is occurring in the Engineering Classroom and Lab outside of the established EERN community. The work presented here provides a valuable insight into how engineers and applied scientists are actively seeking to improve the student experience.

It is hoped that colleagues attending the Symposium for the first time will in future engage with the EERN community and get involved in our future events.

# A Teaching Sandwich Approach to Integrating Classroom and Practical Teaching

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**KEYWORDS:** Teaching at scale; Experimentation; Practicals; Integration; Efficiency

## SUMMARY

A novel and innovative approach to delivering practical teaching has been adopted by the Faculty of Engineering at the University of Sheffield (UoS) to accommodate rapidly increasing student numbers. The new approach provides pedagogical advantages for the students and efficiency advantages for the faculty but exacerbates the potential for the practical teaching to be isolated from the theoretical classroom teaching. Proposed here is the use of a "teaching sandwich", created by scheduling the practical activity between the theoretical lecture and an applied tutorial class. In addition the students were asked to perform two online exercises during their self-directed study time, either side of the practical session. The objective of these exercises was to bridge the gap between the theoretical and laboratory based learning activities. The teaching sandwich approach has been tested on the delivery of a particular topic in a 1st year undergraduate engineering programme and the practicalities of deployment are discussed. Emergent findings show that students value the connections between lab and classroom teaching being made explicit and that the method can be used to make efficient teaching more effective.

## BACKGROUND / CONTEXT

As the number of students studying engineering at higher education institutions increases, the pressures associated with teaching to scale intensify. While certain modes of teaching, such as lectures, are well suited to scaling, others, such as practicals, require substantial investment in resource to cater for increased student numbers. Cost savings can be achieved by reducing the number of practical activities students undertake.

The Faculty of Engineering at UoS has adopted an alternative strategy to provide practical activities to large cohorts. A multidisciplinary team has been created and resourced to deliver all the 1st and 2nd year undergraduate laboratories for engineering programmes. This multidisciplinary approach increases efficiency by leveraging the economies of scale and provides a platform to easily share best practice.



One innovation that is currently delivered for all practical teaching sessions is the “teaching sandwich”. In this context, “sandwich teaching” refers to providing students with tasks to perform before the practical activity, to ensure they are suitably prepared for a meaningful experience in the laboratory and tasks to complete following the practical activity, to allow them to reflect on the work carried out. This helps to reduce the effect of disconnect between the theoretical and practical teaching, but does not address the disconnect itself.

## **AIM AND OBJECTIVES**

The concept of using a teaching sandwich approach to tightly integrate practical teaching in a laboratory with more theoretical teaching in a classroom is presented.

## **RATIONALE**

While there are significant advantages from the multidisciplinary approach to delivering practical teaching, it requires the compartmentalisation and division of responsibility for practical and theoretical teaching. Without sufficient communication and coordination, there is a danger that the student’s understanding of the connection between these activities will be lost.

Presented here is a discussion of utilising the “sandwich teaching” to bridge the gap between the classroom and laboratory based teaching by making explicit the connections between the two, and asking students to pass information from one activity into the next.

## **LEARNING APPROACH**

A “sandwich teaching” model has been applied to a teaching experiment in which pressure loss in flow through porous media is measured and compared to theory. The experiment has been delivered to a group of 35 engineering students at the start of the 2nd semester of their first year. This cohort size was chosen to pilot the approach, which would be easily scalable to significantly greater student numbers at minimal additional resource cost.

In order to learn the topic of fluid flow through porous media, students received a lecture to teach the theory, a tutorial class to apply the theory and a laboratory class to illuminate the concepts in a real context. In the multidisciplinary approach used for practical teaching discussed above, the laboratory class is delivered by a different department than the classroom teaching. To apply the sandwich approach to ensure connectivity between classroom and practical laboratory, three changes have been made:

1. The lecture makes explicit reference to the experimental activity.
2. The introduction of a mandatory, pre-experimental activity ensures the theory from the lectures is revisited and understood before the students arrive.

- The data collected from the experiments is used in a subsequent tutorial class to solve problems.

Using the teaching sandwich approach specifically to couple classroom and laboratory teaching only occurs for this component of the student's taught programme. Students were asked to complete a short survey to gauge their perceptions of the approach and evaluate its success.

## EVALUATION

Students were asked to answer two questions on a 5 point Likert scale. The results from the 13 respondents are shown in figure 1.

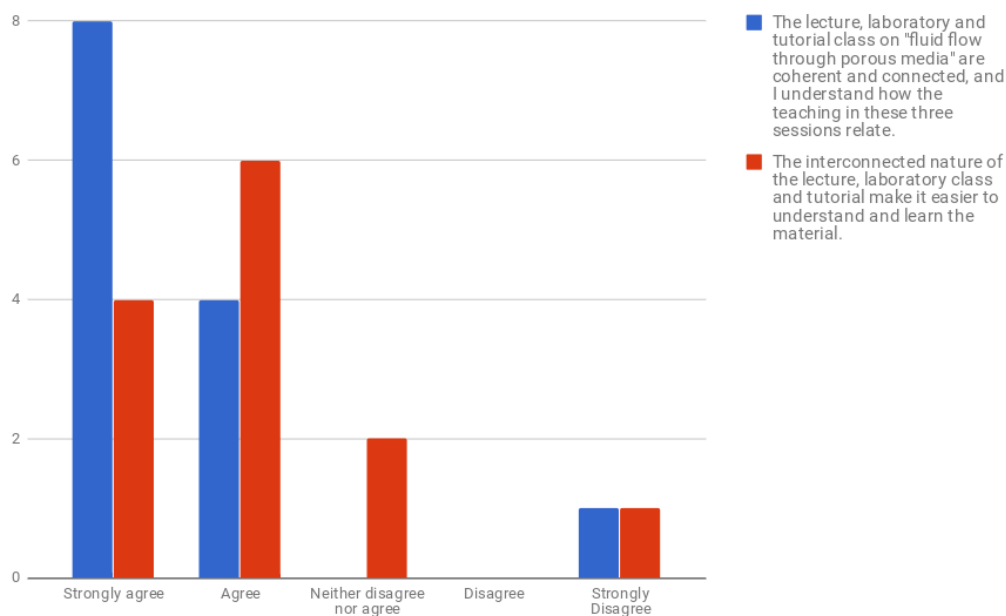


Figure 1: Results of the survey given to students to evaluate the performance of the teaching sandwich approach.

## DISCUSSION

The survey results indicate students valued the explicit connection between practical and theoretical teaching embedded into the teaching sandwich. The data are limited in terms of sample size and self-selection but provide indicative results for this pilot. Some time, effort and communication was required by the lecturing and laboratory academic staff, to ensure the approach was coherent for students, but provides a mechanism to obviate the deficiencies of a multidisciplinary approach to practical teaching at a faculty level, and is scalable to greater student numbers.

During the laboratory session, students performed with independence and autonomy, as a result of being prepared from the pre-experimental activity and the explicit mention of the laboratory activity within the preceding lecture. No initial briefings were

required and student: demonstrator ratios of 1:35 would have been sufficient to respond to student queries. This provides a very efficient use of resources.

In order to deploy this teaching sandwich approach, the sequencing of activities (lecture, lab and seminar), needs to occur in the correct order for all students. To scale this for greater student numbers would require sufficient equipment for many students to run the laboratory exercise in parallel, to avoid over-constraining timetabling processes.

## **CONCLUSIONS & RECOMMENDATIONS**

A teaching sandwich approach can be an effective tool for overcoming a potential disconnect between theoretical and practical teaching, thus facilitating the multidisciplinary practical teaching approach adopted at UoS. Students found that explicit linkage of lectures, laboratory activity, and tutorial classes, in that order, supported the learning of the topic. Ultimately this approach can provide a more effective learning process for students while enabling resource efficiency savings for the institution.

## Agile Engineering Education for Present and Future

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**KEY WORDS: Agile Engineering Education, Ecosystem, Customisation, Inclusiveness, CIVA System**

### SUMMARY

Agile engineering education (AEE) in this context is characterised by **mass customisation** through designing learning modules and learning pathways according to individual learner's needs and targets and **rapid inclusion of new contents** to synchronise engineering education with the evolving technological and societal environment. This paper proposes the strategy of building an AEE ecosystem and sub-systems for resolving a range of fundamental challenges facing engineering education both at present and into the future.

### BACKGROUND

The range of challenges facing engineering education both at present and into the future can be divided broadly into two categories:

*Category 1: Challenges to current engineering education in HE institutions*

- (a) Diverse characteristics of students *vs* uniform requirements of graduates
- (b) Rapid and diverse development of science and technology in real world *vs* limited and delayed coverage by engineering courses

*Category 2: Challenges to engineering education for the society at large*

- (c) Increasing demand on life-long learning by technically trained people due to the fast development in science and technology
- (d) The inherent 'engineering skills gap' between the provisions of engineering courses in HE institutions and the diverse individual requirements of industrial companies
- (e) The need to inform, guide and support young people from an early age to engage with engineering activities and education to increase the supply to engineering profession
- (f) The wide-ranging learning requirements of individuals in pursuing their own dreams

Most of these challenges are generic and will continue into the future, therefore some fundamentally different approaches have to be explored in order to find an effective and sustainable solution.

## AIM

This paper proposes building an ecosystem and sub-ecosystems of agile engineering education (AEE) and demonstrates that the CIVA-type learning packages are strong candidates of the required learning modules of the AEE ecosystem.

## THE PROPOSED AEE ECOSYSTEM

The proposed AEE ecosystem is composed of a collection of learning modules that can be selected and linked together to form learning pathways to achieve the mobility of engineering education for individual learners and to support the knowledge transfer for science and engineering within society. *Mass customization* is realized by designing learning pathways according to the specifications of the starting knowledge base and the target capability of the individual learner. *Rapid inclusion of new contents* is achieved by adding new learning modules to the collection. The capability and the performance of the AEE ecosystem depend on the quality of the learning modules and the ability of generating optimized learning pathways. The quality of the learning modules should be measured by a set of criteria including its value-adding capacity and its effectiveness and efficiency to achieve its full capability. The ability of generating optimized pathways relates to the availability of the number and range of learning modules as well as their relations. The fast developing Artificial Intelligence (AI) is expected to become a major technology to power the generation of learning pathways.

As shown in the next section, since the CIVA-type learning package generates a problem-solving focused structured learning process and, in addition, professional attributes and critical thinking skills are developed through the V&V process, it is highly effective and efficient in adding value to the learning process. Therefore the CIVA-type learning packages can be considered to be strong candidates of learning modules for the AEE ecosystem.

## THE CIVA SYSTEM FOR ENGINEERING EDUCATION

Taking an evidence-based approach as well as considering the changing requirements for graduates and the increasing diversity of the students, the **CIVA** (Coursework-driven teaching & learning process, **I**ntegrated teaching approach, **V**erification & **V**alidation guided quality learning and professional development, and **A**ctive support mechanism) system was developed to achieve a high quality engineering education outcome that was characterised by high academic standard and quality, high inclusiveness and high employability [1].

The **CIVA** system represents a new way to organise the teaching and learning process and can be demonstrated to be an innovative implementation of the pedagogical principles that are recommended widely in HE organisations [5]. Essentially, the CIVA

approach has put an emphasis on addressing the following four aspects that are necessary for establishing an effective and efficient teaching and learning process:

- (1) Motivation of the learner
- (2) Desirable value-adding contents
- (3) Built-in mechanism of self-assessment and further self-improvement
- (4) Customised learning support

The CIVA system has been shown to be effective in

- Motivating, guiding, supporting and training students in their learning process
- Providing effective and efficient learner experience of 'learning through applying'
- Enhancing student employability through the discipline-representative problem-solving type of coursework that integrates the application of multiple key skills and provides a valuable experience similar to that found in professional engineering jobs
- Improving inclusiveness mainly due to the built-in flexibility of the coursework in how learners self-allocate time and resources and the active support mechanism

Several examples can be found in [2-4] that illustrate how the CIVA system has been implemented in teaching several engineering science subjects on a Mechanical Engineering course. Furthermore, some evaluation of the CIVA approach based on student feedback and some discussions on the requirements for adopting this approach are presented in these papers.

## **SOLUTION TO CHALLENGES**

The proposed AEE ecosystem, in principle, can provide solutions to all the challenges listed above. However, taking into account the particular characteristics and requirements associated with Category 1, it is considered separately.

### ***Solution to Category 1: AEE sub-ecosystem with pre-defined learning targets***

For the existing engineering courses in HE institutions,

- (a) Diverse background of the entrants is largely the result of widening participation and internationalisation, and both are highly desirable for the advancement of the human society.
- (b) How the engineering course provision can keep up with developments in the real world and meet the requirements of industry and society in a timely manner is an inherent problem but the faster changing world in recent years has made this difficulty more acute than ever before.

It is predicted that these trends will continue into the future. To resolve the problems, the AEE sub-ecosystem approach may provide a solution.

To be consistent with the existing course structure, the learning pathway should be designed within each unit and the learning target at the end of the pathway should be set as the learning outcomes of that unit. The *mass customisation* feature essentially aims to achieve inclusiveness so a converging preparatory study at the starting point for reducing diversity and an inclusive T&L process are required. The *rapid inclusion of new contents* feature can be realised by adopting the CIVA approach or similar and it provides the flexibility for the actual course contents to be updated.

### ***Solution to Category 2: AEE ecosystem with full customization***

The AEE ecosystem for the society at large will have a more profound significance to how engineering education may exist in future. Building the AEE ecosystem requires the application of the concept of sharing economy to engineering education. Many stakeholders will need to contribute to the AEE ecosystem and benefit from it for its creation and sustainability, as indicated in the summary below. However, it is expected that engineering academics will always play the central role in connecting with other stakeholders and in creating learning modules/pathways of the AEE ecosystem. This will establish the status of engineering academics as a critical force to the prosperity of the future society as their mission will extend from serving their 'enrolled customers' to the creation and maintenance of the 'learning society' for mankind. Engagement in the 'learning society' by a large proportion of the population is of critical importance for the survival and prosperity of the human race in the foreseeable future when people can be looked after in 'comfort and convenience' by the AI powered living environment.

Summary of the main benefits and significance of the proposed AEE ecosystem:

- (a) The AEE ecosystem will help resolve all issues listed above because the **mass customisation** works on the individual basis and can take place at both the starting point and the target point of the learning pathway.
- (b) The AEE ecosystem will **connect** the engineering education in academic institutions, the industrial companies and the potential engineers in a constructive and progressive way. This effective communication will create a multi-win scenario for all stakeholders.
- (c) The AEE ecosystem will provide **customised** learning provision based on the individual starting point and desired learning outcome, so it will be more effective and efficient for the learner and therefore more attractive as well as more practical for people to use on their journey of pursuing their own dreams.
- (d) The AEE ecosystem will **motivate the engineering academics** to engage with the latest scientific and technological developments as the learning modules that they create will contribute to building the 'learning society' and can generate a wide and long lasting impact. Furthermore, such engagement will increase their capability and opportunities to collaborate with industrial companies, which is beneficial to both industry and engineering education.
- (e) The AEE ecosystem will **motivate the industrial companies** to work with academic institutions as their contributions to the learning modules will help recruit better qualified engineers for their industry.

- (f) The AEE ecosystem will facilitate the **funding** for implementing the government Industrial Strategy to be spent more effectively as the Learning Centre as part of the AEE ecosystem needs to be equipped with high standard and up-to-date software/hardware facilities and personnel.

## CONCLUSIONS & RECOMMENDATIONS

The proposed AEE ecosystem is an attempt to explore ideas for finding a solution for resolving the widely recognised deficiencies of the current engineering education and for building a 'fit-for-purpose' engineering education for future society.

Building the AEE ecosystem requires the application of the concept of sharing economy to engineering education and it will generate a multi-win scenario for all the stakeholders and the society as a whole. Engineering academics should play a central role in the creation and maintenance of the AEE ecosystem and their contributions to the 'learning society' for mankind will be recognised with a wide and long lasting effect.

The CIVA system presented is an innovative approach to engineering education. It has been shown to be effective in improving student engagement and be efficient in adding value, thus increasing value-for-money of the learning process. Therefore, the CIVA system should be able to contribute to the engineering education reform that many HE institutions around the world have been exploring.

Furthermore, the CIVA-type learning modules are recommended for the proposed AEE ecosystem. When a large number of such learning modules covering a wide range of topic areas have been created and the capability of generating optimal learning pathways has been developed, the ecosystem of AEE will be formed.

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## **The Year in Computing Initiative**

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**KEY WORDS: Curriculum; Student Experience; Non-Traditional Students**

### **SUMMARY**

The *Year in Computing* is a newly launched programme in the School of Computing at the University of Kent that allows students from any discipline (other than computing) to spend a year exclusively studying computing as part their degree. It is a structural innovation that addresses problems of underrepresentation and lack of diversity in Computing in a way that other Schools and Universities can adopt.

### **CONTEXT**

The *Year in Computing* is a self-contained year which students take either between their second and third year of study (similar to existing structures for a *Year in Industry*) or after the third year. The idea of an intercalated year in another subject has origins within the UK in medical schools, who have long encouraged their students to take a year out of undergraduate medical studies to study another discipline (traditionally, a scientific discipline such as biochemistry; but, more recently topics such as medical humanities are offered). Such programmes typically involve students attending a selection of courses alongside early-stage students in that subject. Indeed, one of the precedents for our *Year in Computing* is a University of Birmingham programme where students are enrolled in existing first/second year Computer Science modules. Our approach is different: students are taught as a separate cohort, with a curriculum focused around a specific, coherent set of technologies, allowing them to reach a high standard of skill with those technologies whilst also learning broad informatics principles.

The programme's curriculum was purposefully designed to focus on the web which exposes students to both frontend and backend technologies. And as students in the programme are taught in a separate cohort, not together with other undergraduate students, all students (regardless of their "home" discipline) take the same modules at the same time, which obviates any scheduling problems. Students who successfully complete the *Year in Computing* graduate with their original degree title augmented with the designation "with a Year in Computing". While students' results in the *Year in Computing* appear on their transcript, they do not affect the classification of their degree, which is based purely on their performance in their "home" discipline.

The *Year in Computing* was first offered in the 2016/17 academic year when some 70 students applied for admission. Of those, 45 students were offered places and 35



started the programme. 40% of the students in this cohort were women. This is extremely unusual for a UK Computing programme, where the proportion of women is more typically 15%. The students in the programme also come from a wide variety of disciplines, including most Schools at the University, with 47% of the students completing non-STEM degrees. The 2017/18 interviews have just finished with over 90 applications and 50 offers made (and similar proportions of women and students from non-STEM fields), justifying our assumption that this is a sustainable programme.

## **RATIONALE**

This initiative adds value to existing degrees by offering students from other disciplines the opportunity to develop skills both employers and students are seeking. In doing so, the programme reaches students who would not otherwise have studied computing; it provides an opportunity for students to study computing later in their academic careers without committing to a conversion MSc course.

The model we have developed for the *Year in Computing* is pedagogically appropriate (students are taught in a cohort and not mixed with other undergraduate students in CS; courses are purposefully designed for the programme) and more sustainable than any given joint-honours offerings which require significant administrative overhead for students from each additional discipline.

## **AIM**

We wanted to understand students' motivations for enrolling in the *Year in Computing*. Why did *these* students choose to study computing now, after having initially decided to study another discipline at university?

## **METHODOLOGICAL APPROACH**

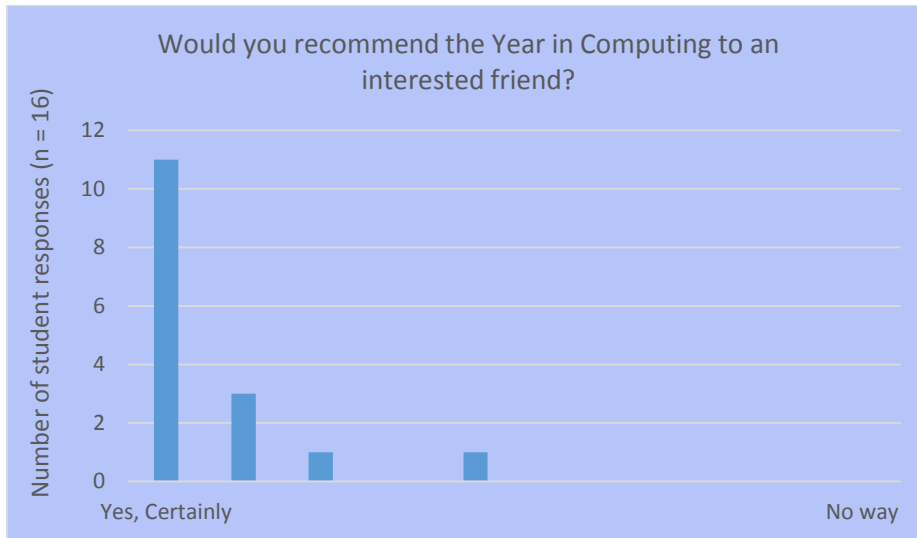
We draw on the application statements students were asked to submit indicating why they were interested in taking part in the *Year in Computing*. We also conducted two surveys (using Google Forms and SurveyMonkey), one at the end of each term, to better understand students' experiences in the programme. 12 out of 34 students (35%) responded at the end of the autumn term and 17 students (50%) responded at the end of the spring term. For the most part, these surveys contained questions about students' expectations, their personal and professional goals, and their experiences in the programme to date. We subsequently extracted themes from the free text responses.

## **EMERGENT FINDINGS**

Students expressed different reasons for enrolling in the programme: some were interested in enhancing their employability (within their home discipline), others wanted to gain an understanding of technical systems. Again others took part to challenge themselves academically and for some it presented the chance to study

computing they never had. We have reported an analysis of these themes, as well as the role of students home discipline in influencing their experiences, in [1].

Students also responded positively when asked whether they would recommend the programme to a friend: such indications of Net Promoter Score (NPS) are a highly regarded loyalty metric.



We intend to follow up with these students after their graduation to explore the longitudinal effect of the *Year in Computing*.

## DISCUSSION

We have reported initial findings and examined the experiences of a group of non-traditional students in the *Year in Computing* in this work. The *Year in Computing* changes the status quo by providing opportunities and making computing attractive for students who otherwise would not have studied the subject.

## CONCLUSIONS & RECOMMENDATIONS

This initiative is a novel approach that can be implemented within the existing structures of universities. Indeed, the University of Sussex has already adopted this model and other institutions (e.g. the Universities of Essex and Nottingham) have expressed interest in it. At the University of Kent itself other schools have begun using this model to explore offering a *Year in Arts* and a *Year in Quantitative Research*.

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## **CASE STUDY: Laboratory Planning and Model Simulation Software**

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**KEY WORDS: Laboratory, Planning, Scheduling, Management, Utilisation**

### **SUMMARY**

Laboratory sessions (labs) are a critical part of enhancing the student learning experience. Laboratory planning is a three stage process; evaluating current lab conducting systems, adapt sessions to address issues and use model simulation software to demonstrate lab implementation. This case study demonstrates how these stages can be effectively implemented for a practical skills based module Skills For Engineering (SFE) conducted for every discipline under the Faculty of Engineering and Informatics at University of Bradford.

### **BACKGROUND**

An issue faced by industrial employers and academics is that upon graduation, students have a good grasp of engineering theory but lack practical skills to apply this knowledge. The University of Bradford developed the SFE module, a year-long general module for every engineering discipline in the Faculty of Engineering and Informatics, to address these issue at source.

### **RESEARCH QUESTION**

How can software be used in laboratory planning to maximise time spent in labs without compromising student direct contact time?

### **AIM**

The aim of the study was to provide a case study evaluating the current systems used in laboratory planning and demonstrate how model simulation software can be incorporated into planning for modules like Skills for Engineering.

### **RATIONALE**

Strategic planning is a critical aspect of the education system which adapts to meet industrial demand. This is particularly important with respect to laboratories as their successful management has a two-fold impact, enhancing the student learning experience and energy efficient yet effective resources utilisation. Software such as ARENA can be used for effective laboratory planning.

## METHODOLOGICAL APPROACH

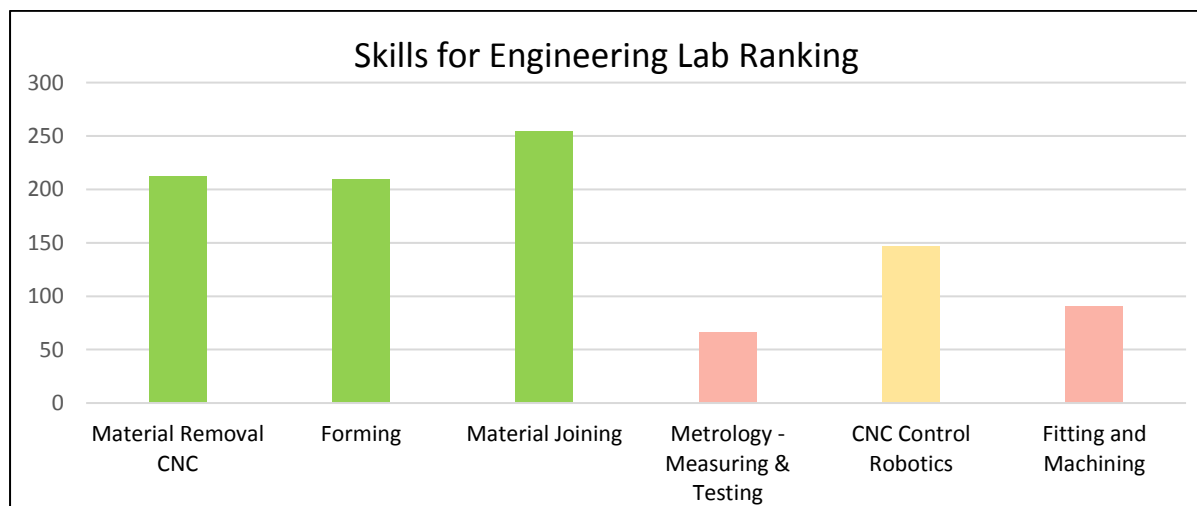
The first step was identifying laboratory design, planning and preparation variables. For this study the university's module questionnaire was modified for SFE as shown in Figure 1 below. To reduce response burdening the questionnaire was distributed via email (Alder et al. 2011 and Charles et al. 1999). Lecturers and technicians interviews followed a similar structure to the student questionnaire to identify laboratory management variables. The results were then used to plan a laboratory session on ARENA that would enhance the student learning experience and highlight system success factors (ARENA Simulation Software 2017, Anderson et al. 2011).

## KEY FINDINGS

### Stage 1: Evaluation of current systems used in laboratory planning

Rating scales quantifiably assess laboratory planning variables. The highest scoring lab was Material Joining and Metrology was the lowest. The most enjoyed labs were interactive with sufficient technical support, whereas demonstrational (Metrology, CNC Control Robotics and Fitting & Machining) labs were enjoyed less.

*Figure 1: Student satisfaction lab rating*



### Stage 2: Development of laboratory sessions to address planning factors

#### Technician Focus Group

Technicians are each assigned to a particular workshop, however they are versatile based on demand. Their work tends to involve laboratory preparation, assisting research projects and general maintenance. The main findings from the interviews can be summarised as follows.

- Technicians conduct SFE sessions, however lecturer presence would aid in explaining course significance.
- Increasing equipment range in the laboratories can increase student competent in a laboratory.

## Lecturer Interviews

An analysis of the lecturer interviews led to the following observations:

- Staggering student arrival times can double laboratory capacity.
- Colour coding tasks increases efficiency.
- The optimum group size is 4 students for maximum contact time with supporting staff.
- Having additional tasks encourages students to take charge of their learning, rewards hard work and facilitates for interdisciplinary knowledge transfer in general modules.

## DISCUSSION

Simulation software has potential for use in engineering education during laboratory session planning with regards to quantifying laboratory capacity, tracking equipment utilisation and assisting with visualising how it will be conducted. Software such as ARENA, FlexSim, Dassault 3DEXPERIENCE, Factory CAD, Simu18 etc. are a few examples of software that can be used for this application. For the purposes of this case study ARENA was selected as it is commonly used at University of Bradford by both academics and students.

### Simulation Assumptions

- Students move through the laboratory sequentially
- Each workstation is a collective of one type of machinery and each equipment varies from station to station (Choi and Wang 2012).
- All jobs have to pass through each station as demonstrated by the process lines as demonstrated in Figure 4 (Dai et al. 2013).

### Laboratory Capacity

Assessing laboratory capacity improves engineering education as it encourages more effective facilities usage.

### Laboratory Completion Time

ARENA simulates the lab and tracks the average times taken to complete tasks, accounting for waiting, transfer and other miscellaneous times in a lab. Figure 2 shows an average 75 minutes completion time. This information can be used to predict student working rate.

Figure 2: Student time in the laboratory

| Replications: 10 |         | Time Units: Minutes |                 |                 |               |               |
|------------------|---------|---------------------|-----------------|-----------------|---------------|---------------|
| <b>Entity</b>    |         |                     |                 |                 |               |               |
| <b>Time</b>      |         |                     |                 |                 |               |               |
| VA Time          | Average | Half Width          | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Student          | 67.9688 | 0.53                | 66.2311         | 68.6628         | 57.5339       | 81.0164       |
| NVA Time         | Average | Half Width          | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Student          | 0.00    | 0.00                | 0.00            | 0.00            | 0.00          | 0.00          |
| Wait Time        | Average | Half Width          | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Student          | 5.6942  | 0.77                | 3.3691          | 7.3700          | 0.00          | 21.3730       |
| Transfer Time    | Average | Half Width          | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Student          | 1.5000  | 0.00                | 1.5000          | 1.5000          | 1.5000        | 1.5000        |
| Other Time       | Average | Half Width          | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Student          | 0.00    | 0.00                | 0.00            | 0.00            | 0.00          | 0.00          |
| Total Time       | Average | Half Width          | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Student          | 75.1630 | 0.82                | 72.5851         | 76.4269         | 59.0339       | 91.6746       |

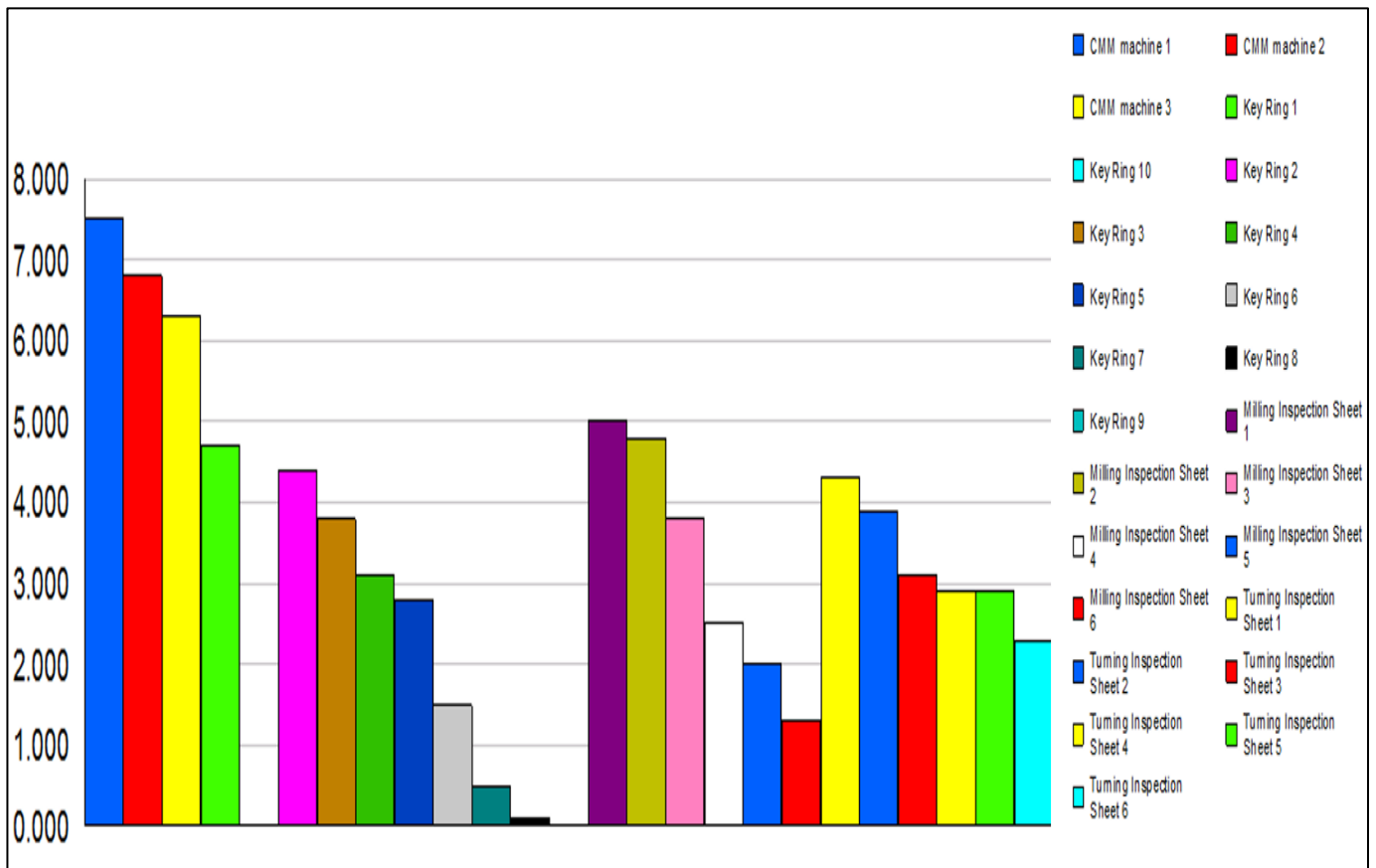
## Waiting Time

The greatest waiting time shown was at the Coordinate Measuring Machine (CMM) station.

## Equipment Database

ARENA can be used to create an equipment database and identify the most utilised work station. Figure 3 shows it to be the CMM station. This information can be used by lecturers to identify where more resources may be needed to improve the quality of education.

Figure 3: Number of students who used each piece of equipment



## CONCLUSION

In engineering education laboratory sessions play a critical role in the student learning experience, increasing understanding and engagement with the course content. Proper planning and management of labs ensures that students get the best learning experience which is the first step to bridging the skills gap. It is because of this that the labs are regularly refurbishment and modules redeveloped; with new facilities, new module content new exercises need to be designed. For such a task an easily adaptable system is required to assist in the planning process to make it more effective to meet the needs of an ever evolving industry and fluctuating student recruitment.

Model simulation software, for instance ARENA, is a fast and effective way for simulating a process before using resources to implement it. It can be used to simulate future labs during the design stage and from resultantly resolve scheduling issues, estimating amount of resources required and session quality. These are only a few variables that make it a great asset to effective planning for engineering education.



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## Electronic & Electrical Engineering in the UK: Bridging the Skills Gap – The Case for Curriculum Change

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**KEY WORDS:** Skills Gap: Electronic Engineering Education: STEM Decision Pipeline

### SUMMARY

Technology is a catalyst for social and economic change in our constantly evolving world. It is only a single generation ago that having a landline phone was the pinnacle of communication technology and marked out a household as privileged and technologically advanced. Currently, two thirds of the U.K. population now owns a smartphone containing highly complex processors and capable of advanced communication technology. Electronic products have become essential to society and are a fundamental enabler of our modern, connected, lifestyle. Technological advances will continue to lead to the development of innovative products transforming the way we live; from health care and medicine to entertainment. It is predicted that the near future will see the evolution of 'smart cities' with transportation, energy consumption, water use and security monitored, regulated and improved through advances in electronic and electrical engineering. The strategic challenges faced by society associated with cyber threats and energy security, are all also underpinned by electronics.

However, there is a fundamental problem for the UK. Our participation in and leadership of these technological advances is being limited by a chronic skills shortage in electronic engineering. Over a number of years, too few students have been studying electrical & electronic engineering. This in combination with an ageing workforce means that there are insufficient graduate engineers to drive forward innovation and progress. This paper examines the nature of the electronics sector in the UK, considers reasons for the graduate skills shortage and offers a potential solution to this shortage through proposed changes in secondary education.

### BACKGROUND / CONTEXT

The UK Electronics sector is a world-leader and one of the keys to the success of the UK economy. Engineering contributed £455.6 Billion to the UK's economy in 2014. The Gross Value Added (GVA) of engineering businesses was more than retail, wholesale, financial and insurance sectors combined (Engineering UK, 2017). Within engineering, the Electronic and Electrical Engineering sub-sector contributed more than any other (GVA £131 Billion) and employed 1.5 million people (Engineering UK, 2016, p.23). This is a sector that is continuing to grow and the demand for graduates is outstripping supply. Only 3,510 UK students enrolled on first degrees in Electronic and Electrical Engineering in 2016 (UCAS, 2016). Approximately 22% of employers in

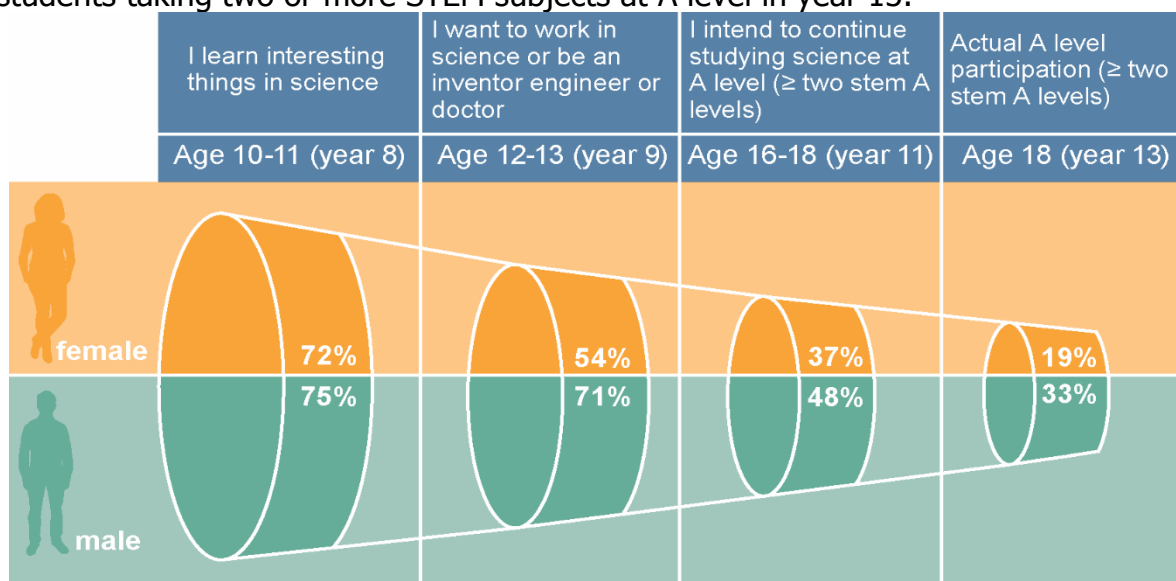


this sector have reported problems in recruiting engineering graduates (The IET, 2016). A survey conducted by the CBI revealed that 46% of employers reported a shortage of STEM graduates (Engineering UK, 2016, p.262). Without any intervention this problem will only get worse, the overall number of 18 year olds in the UK is due to drop by around 9% in the decade to 2022 (Engineering UK, 2016, p.45). This shortage is also compounded by the gender gap in STEM subject uptake. The WISE Campaign reported that female students make up only 21% of those taking A-level Physics and that this percentage hasn't improved over 30 years of interventions (WISE Campaign, 2016).

It is clear there is a compelling case to tackle the ongoing skills shortage in this sector and to support the Electronic Systems Community (ESCO) vision of "*making life smarter for everyone, to drive commercial success and, ultimately, economic growth for the country*" (ESCO, 2014). Beyond this, electronics is the fundamental enabler of such potential paradigm shifts as the Internet of Things and Industry 4.0, for most technology professions there is a need to be electronics literate.

## Education & the STEM Decision Funnel

Research conducted by Kings' College as part of the ASPIRES research programme (Kings' College, 2013) identified a phenomenon termed the STEM Decision Funnel where the number of students engaging with STEM as an interest, potential career and academic subject reduces significantly as secondary education progresses. This is represented in diagram below (Figure 1). The evidence demonstrates that both male and female students in the final year of primary school have relatively high levels of interest in science (74% and 72% respectively). Interest in science as a career, the expression of interest in and then actual continuation of two or more STEM subjects at A level is demonstrated by a diminishing number of students as secondary school progresses (Kearney, 2016, p.6). While male and female students leave primary education with an almost equal interest in science, the divergence in interest levels between the genders sets in within only two academic years of secondary school, and increases throughout secondary education approaching a 2:1 ratio of male to female students taking two or more STEM subjects at A level in year 13.



**Figure 1. The STEM Decision 'Funnel'.**

Data for A level choices in 2017 (Table 1) clearly indicates problems in recruitment of students for Physics, an extremely useful subject for potential electronic and electrical engineers. This subject also demonstrates, as previously noted, a stark gender imbalance (Figure 2). More positively, Mathematics remains the most popular subject studied by pupils at Key Stage 5 / A Level (Table 1) and has a more equal balance of male to female students, with almost 40% of those studying it at Key Stage 5 / A Level being female (Figure 2).

Table 1 Top GCE A-level subjects in 2017 by entry

| Ranking | Subject                 | % of total | Number of candidates |
|---------|-------------------------|------------|----------------------|
| 1 (1)   | Mathematics             | 11.5       | 95244                |
| 2 (2)   | Biology                 | 7.5        | 61908                |
| 3 (3)   | Psychology              | 7.1        | 58663                |
| 4 (5)   | Chemistry               | 6.3        | 52331                |
| 5 (4)   | History                 | 6.1        | 50311                |
| 6 (6)   | English Literature      | 5.6        | 46411                |
| 7 (7)   | Art and Design Subjects | 5.3        | 43653                |
| 8 (8)   | Geography               | 4.6        | 37814                |
| 9 (9)   | Physics                 | 4.4        | 36578                |
| 10 (10) | Sociology               | 4.2        | 34607                |

(2016 ranking in brackets)

Differences between male and female A level subject choices – summer 2017

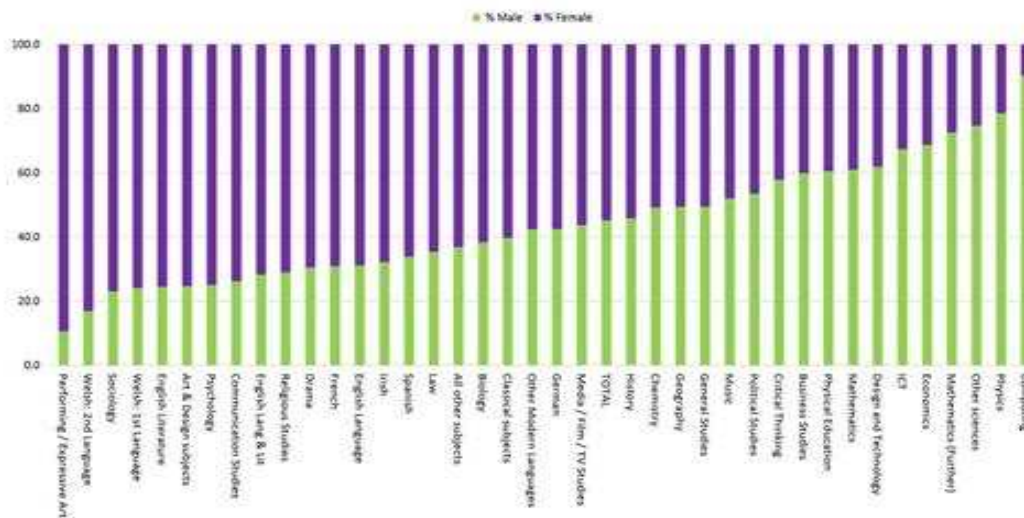


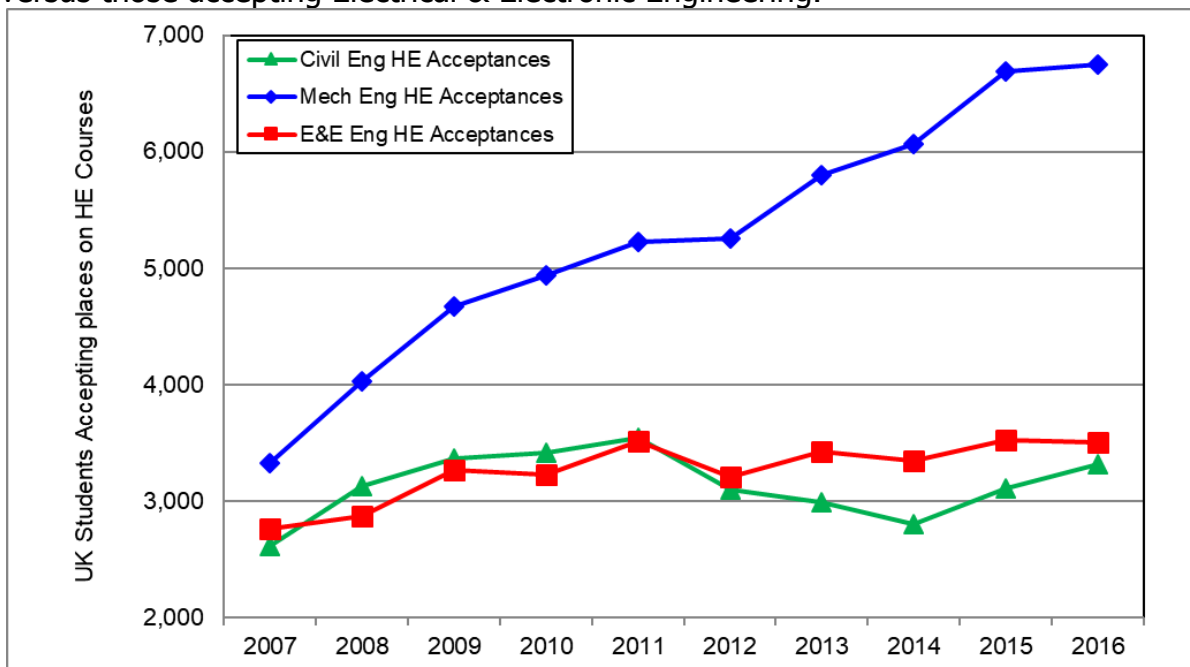
Figure 2. JCQ National Results for 2017.

## Electronic & Electrical Engineering & University Applications

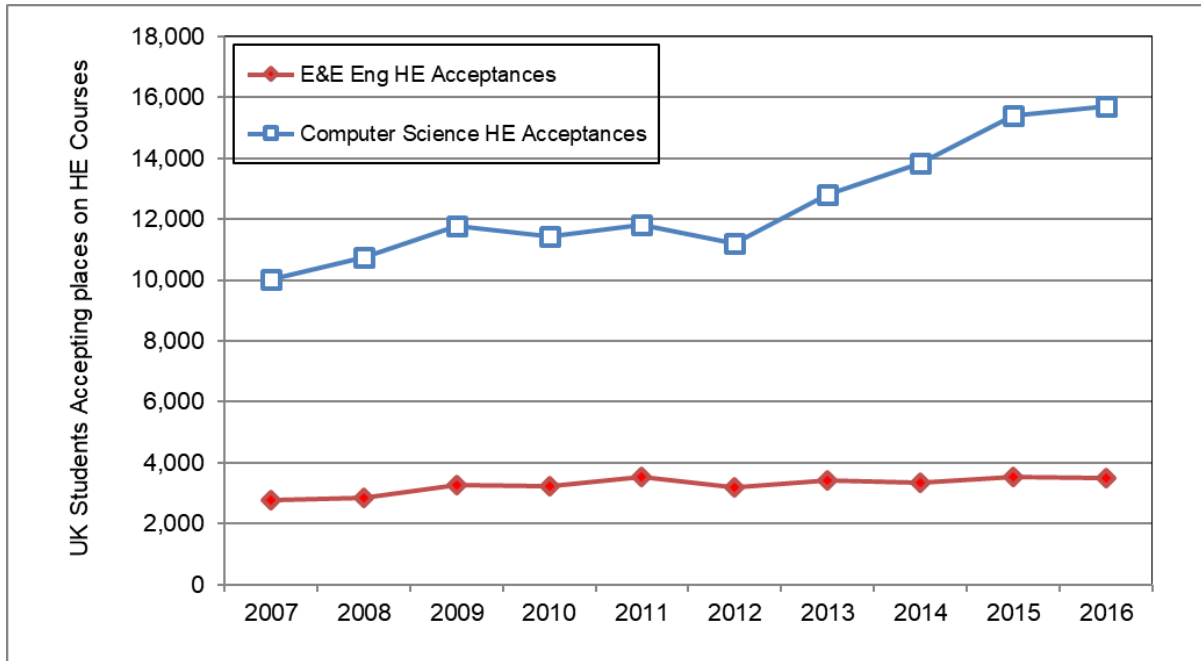
In order to study electronic and electronic engineering at university, maths is generally the only specified essential A level, further STEM A-levels are looked favourably on, but are not essential. So with a healthy uptake of Mathematics A-level students we should not be seeing any particular problems with recruiting appropriate students at University level. The data available from UCAS does show an improvement in recruitment for engineering degrees of 64.4% from 2007 to 2016 with specific Electronic and Electronic Engineering degrees improving by 27%. The increase in

electronic and electrical engineering recruitment does not compare favourably with the 66.7% increase demonstrated by Computer Science and the 103% improvement demonstrated by Mechanical Engineering in the same period (Figures 3&4). When we consider the absolute recruitment figure for Electronic and Electronic Engineering we can see that the numbers are low in comparison to other subjects and that lower UCAS tariffs are accepted. Figures 3 and 4 clearly show the relative low numbers accepting university places in Electrical & Electronic Engineering and the steady-state of this low figure over many years. There is clearly a problem with the popularity of Electronic and Electrical Engineering as a degree choice.

Figure 3 compares three specific intakes of UK students, those of Civil, Mechanical and Electrical & Electronic Engineering undergraduate degrees, whilst Figure 4 makes the comparison of those UK students accepting a first degree in the Computer Sciences versus those accepting Electrical & Electronic Engineering.

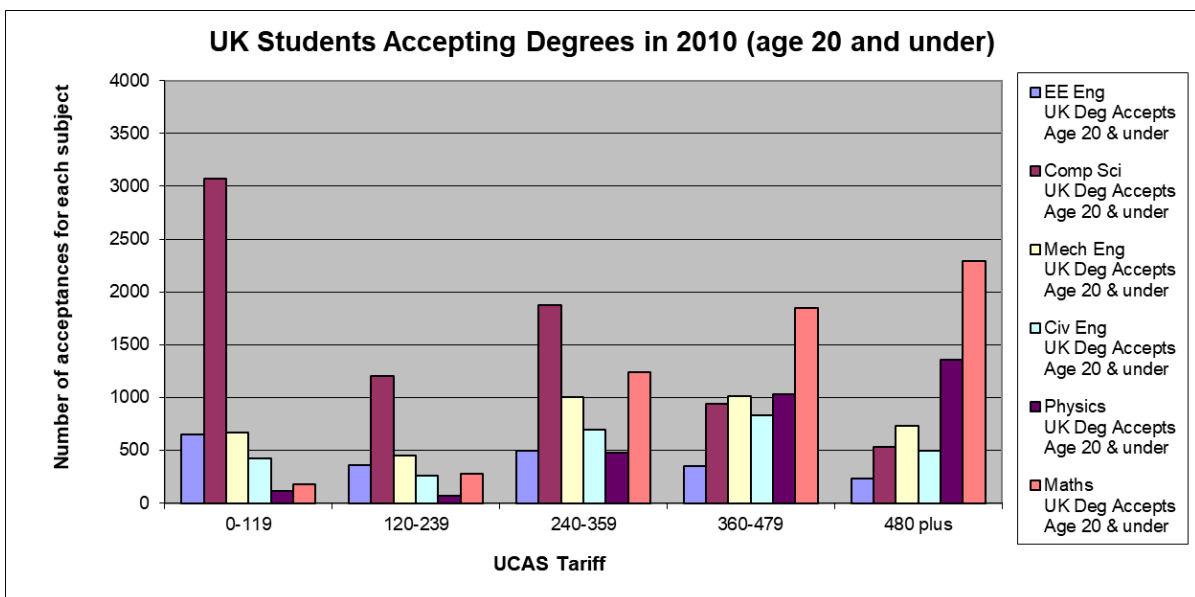


**Figure 3. A Comparison of university subject intake for Electrical & Electronic Engineering versus Civil and Mechanical Engineering (UCAS, 2016).**

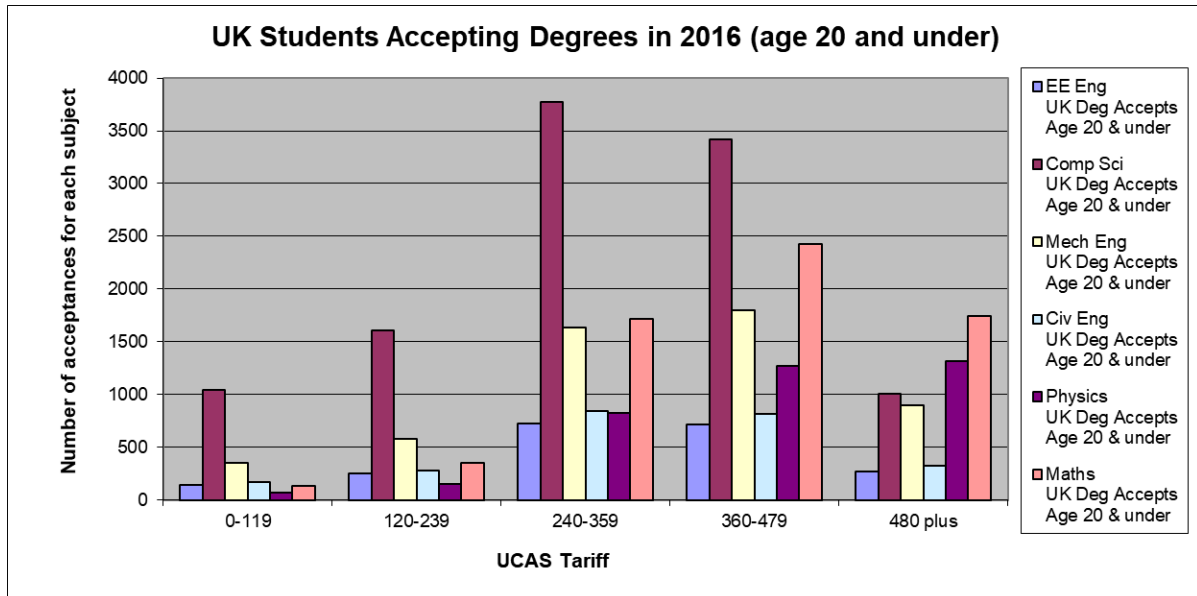


**Figure 4. A Comparison of university subject intake for Electrical & Electronic Engineering versus Computer Science (UCAS, 2016).**

Figures 5 and 6 present a 2010 and a 2016 snap-shot of UK students (aged 20 and under) accepting degrees, in many of the main subjects under the STEM banner. The observations to be made from the data presented in these figures are: the positive gradient in UCAS points of post 18 years old's accepting degrees in Physics and Mathematics; the negative gradient of those accepting degrees in Electrical & Electronic Engineering and Computer Science (albeit with a shift to the right in the 2016 snapshot); and the fairly steady-state of those accepting degrees in Mechanical and Civil Engineering degrees. However, the data in both figures clearly demonstrates that school leavers with the highest UCAS tariffs choose not to study Electrical & Electronic Engineer (as compared to the other subjects).



**Figure 5. A 2010 spot analysis of university subject intake verses UCAS tariff point (source: UKESF using UCAS data).**



**Figure 6. 2016 spot analysis of university subject intake verses UCAS tariff point (source: UKESF using UCAS data).**

There is also other interesting data to be drawn out regarding the age of students starting Electrical & Electronic degrees. UCAS data reveals that in 2016, 63% of U.K students beginning an Electronic & Electrical engineering degree were 18/19 years old. Therefore, 37% of those starting Electrical & Electronic Engineering degrees were older than 19. This is a relatively high number of over 19s and may indicate that after a year outside of education students are more aware of the benefits of a career in Electric and Electronic Engineering.

### **DISCUSSION: Problems in Electronic & Electrical Engineering degree recruitment & attempting to bridge the gap**

What are the underlying reasons for the relative paucity of STEM 'minded' pupils, particularly academically high-achieving ones directly from secondary schools, going on to study Electrical & Electronic Engineering? It is not claimed that all of the reasons will be identified here, but some possible reasons are outlined below:

- Electronics is a hard and abstract subject; unable to be seen and without movement. Mechanics are visual and practical and hence more attractive as a subject. Electronics is too hidden and 'under the radar'; it can be difficult to describe and explain, especially at primary & secondary school level.
- Electronics is not a core part of the Physics curriculum at GCSE. Also, very few secondary schools offer it as a standalone subject at either GCSE or A-Level.

- A-Level Mathematics includes specific and substantial Mechanics modules, which strengthen interest and understanding of mechanical forces and Newtonian Mechanics and its place and impact in the world.
- There is a lack of awareness about the size, impact and diversity of the Electronics Sector in the UK which has an adverse impact the perception of Electronics as a viable U.K career. There is a common (mis)perception that Electronics is only thriving in other countries and not in the UK. Secondary school students are not actively encouraged to pursue an interest in Electronics as they don't believe it will lead to a rewarding and worthwhile career.
- The success of the *Computing at Schools* campaign and other initiatives (e.g. Code Clubs) may have attracted some of those previously intending to study Electrical & Electronic Engineering to Computer Science. Until recently, there have been less STEM interventions focussed on promoting Electrical & Electronic Engineering in schools.
- Supported by media interest in high profile projects, for instance the Bloodhound SSC programme to produce a car capable of 1,000mph, the Institute of Mechanical Engineering (IMEchE) is very effective in promoting mechanical engineering.

Of these reasons, it is acknowledged that others exist around aspiration and promotion, which can be considered as 'pull' factors. However, it is our contention that the most significant reason is to do with the curriculum at secondary school. The nature of the current curriculum, in effect, 'pushes' pupils away from an interest in Electrical & Electronic Engineering towards other sorts of Engineering, especially Mechanical.

We believe this is due to the way forces are taught in the secondary school curriculum and how they relate to the different engineering disciplines. In attempting to explain what the three main subjects of Mechanical, of Electrical & Electronic and of Civil Engineering concern themselves with, and a useful definition that could be utilised in secondary education, is as follows:

- ***Mechanical*** – concerning itself with the controlled flow of *masses* in motion.
- ***Electrical*** – concerning itself with the controlled flow of *electrons* in motion.
- ***Civil*** – concerning itself with the controlled flow of the *environment* in motion.

Using this definition the point of their similarity is made – they all concern themselves with the controlled flow of energy in three of its many manifestations or forms. Each engineering discipline is concerned with energy control, but within different physical mediums. The significance resides in the difference in magnitudes of these physical mediums and the Newtonian Forces involved. Equations 1 and 2 show in basic form



the magnitudes of the mass-mass ( $F_M$  - Newtonian) and the charge-charge ( $F_E$  - Coulomb) interactions. In these equations,  $K$  represents the medium between the masses or the charges and  $d$  represents the separation distance.

$$F_M = K \frac{M_1 M_2}{d^2} \quad \text{Newtons} \quad (1)$$

$$F_E = K \frac{Q_1 Q_2}{d^2} \quad \text{Newtons} \quad (2)$$

If we were to ratio  $F_M:F_E$  our best scientific estimates currently puts this as a ratio of some  $1:10^{28}$  (Young & Freedman, 2012). The difference in magnitudes is extremely large. As a charge in motion constitutes the source of a magnetic field we should strictly compare the mass-mass interaction with the electromagnetic interaction. Either way, if this were a fact demonstrated within either A-Level Physics or Mathematics then perhaps the impact that the subject of Electrical & Electronic Engineering on the world around would be better understood.

It is our contention that electromagnetic forces are insufficiently represented in the curriculum of the STEM subjects of Mathematics and Physics. There has been and there remains a greater emphasis on mechanical forces and this leads to a conscious bias towards studying related subjects beyond Key Stage 5/A levels. To correct this bias, electromagnetic forces need to be given equivalent prominence to mechanical forces throughout the STEM curriculum and in-fact, given their basic similarity, shown alongside each other.

## CONCLUSION

Electrical & Electronic Engineering is at the heart of the current technological revolution and Electronics fundamentally underpins a number of industries crucial to the UK's future prosperity. However, too few students – especially academically high-achieving ones – are studying the subject at university and this has created a chronic and worsening graduate skills shortage in the sector. There are number of possible reasons for this situation, both 'pull' and 'push'. The most significant one is the current approach to teaching STEM subjects at secondary schools, with an overly heavy focus on mechanical forces in the curriculum.

In order to address the skills shortage, it is argued that electromagnetic forces need to be given equivalent prominence as mechanical forces throughout the STEM curriculum. If this change was made within the current A-level Mathematics curriculum, given its popularity as an A-Level choice and the healthy representation of female students enrolled on A-level Mathematics we may go some way to addressing the both shortage of students and male bias in student numbers applying to study Electronic & Electrical Engineering degrees.

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## Enhancing student engagement and active participation via a flipped learning approach

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**Keywords:** Flipped-Learning, Video Lecture, Foundation Year, Feedback, Large Groups

### **SUMMARY**

The aim of this discussion paper is to consider whether a Flipped-Learning approach may improve student engagement on a Physics Module within an Engineering Foundation Year Programme. The students enrolled on the module originate from a diverse range of academic, social and demographic backgrounds and are taught in large groups of between 100 and 300 students.

### **BACKGROUND**

Over the past few years Flipped-Learning approaches have become increasingly popular within Engineering Education; providing students with the means by which they can prepare for lectures in advance, whilst making time in lectures for deeper exploration and explanation of concepts. Identified as an ideal platform for enhancing independent learning and logical reasoning, Flipped Learning is a pedagogical approach whereby the direct teaching moves from the 'group' learning space to the 'individual' learning space, resulting in greater student engagement and increased interaction between the teacher and students. It is this shift in focus that motivated the intervention discussed here.

### **AIM AND OBJECTIVES**

The main objective of introducing Flipped-Learning is to investigate whether the approach is suitable at Foundation Year level in terms of enhancing student engagement and attainment in what is generally perceived to be a 'difficult' subject (Physics). Concurrently, using Action Research Methodologies an Engineering Education Research study is being conducted in order to critically evaluate the effectiveness of the approach and its impact on learning. The Action Research Study is not the focus of this paper as the work is very much in the early stages.

### **RATIONALE**

As with much teaching in Higher Education, a lack of student attendance in Lectures at Foundation Year level has the potential to severely disrupt students learning – particularly when introduced to new topics or concepts. Flipped-Learning aims to

eradicate this interruption, providing the means by which an individual's absence from the classroom can be taken account of in such a way so as not to detract from them learning the material. Likewise, should the module tutor be absent, learning can continue with minimum disruption (Barkley, 2005).

Whilst that the approach requires students to adopt a proactive and independent approach to their studies, the responsibility for preparing the materials and planning the learning activities remains very much with the tutor. Thus in introducing Flipped-Learning at Foundation Year level, much thought, care and attention was paid to assure that the Learning Outcomes could still be achieved.

## **METHODOLOGY**

In adopting a Flipped-Learning approach to teaching Foundation Year Physics, a short video lecture is provided in advance of each session outlining the main concepts and theories. This allows the students with the means by which they can access the material at their own pace and in their own space. The video is supported by a number of bespoke digital and online resources, all of which are made available via the VLE. Students are instructed to watch the video and access the materials prior to the lecture. They are also required to make a short note of any questions raised by the material which, together with a summary of their learning, they are required to bring to the lecture.

To keep track of progress an on-line multiple-choice assessment tool has been introduced. This provides direct feedback to students regarding enabling them to reflect and act upon any difficulties whilst allowing the lecturer to adapt the subsequent lectures accordingly.

In the classroom itself, students are split into two separate groups dependent on 'ability'; each group was then further divided into smaller 'work-groups'. The Flipped-Learning approach means that the classroom sessions provide the means by which students are able to learn collaboratively, applying their skills to a range of activities using higher order thinking. 'Tutors' are given time to work with students on a small-group and one-to-one basis, whilst student-centred group activities in the classroom allowed students to explore their thoughts in a supportive environment.

## **DISCUSSION**

Foundation Year students bring with them a unique set of challenges; many of them have not achieved the required pre-requisite GCE 'A' levels needed to enter directly onto their chosen undergraduate programme; whilst others have previously studied for different qualifications (including BTECs) at College. Finding a teaching method which encourages independent learning and promotes student engagement at Foundation Year level is not easy, particularly when there can be up to 300 students in the classroom.

The Flipped-Learning approach discussed here is very new, having been developed for use in this academic year. Hence it is too early to say whether it is working as

such. However, the approach will be fully evaluated at the end of the academic year and a comparison made with previous years in terms of overall module scores, student satisfaction and progression.

## CONCLUSION

Whereas with the traditional teacher-centred model, the teacher is the key source of information, the “sage on the stage” (King, 1993), with Flipped-Learning there is a deliberate shift from a teacher-centred classroom to a student-centred approach, where in-class time is meant for exploring topics in greater depth and creating richer learning opportunities.

At Foundation Year level students move from being the product of teaching to the centre of learning; Flipped-Learning allows students to become actively involved in knowledge formation, providing opportunities to participate in and evaluate their learning in a manner that is personally meaningful. In conclusion, whilst the approach appears to be working well, with students reviewing and learning content prior to attending the lecture, it will be some time before the value of Flipping-Learning in the Foundation Year Physics Classroom will be fully understood.

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# Section 3: Time for Change: Moving Forward – Interventions & Actions.

The final section of the Symposium Findings brings together those papers at the cutting edge of Engineering Education Research and Practice, providing an insight into some of the innovative approaches currently being developed and rolled out. The final paper in particular relates to NMITE, an exciting concept which is proposing completely new way of educating future engineers.

## Case Study of Leading Educational Change in a Research-Intensive Engineering Faculty.

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**KEY WORDS: Leadership, Change Management. Curriculum Development, Challenging the Status Quo**

### SUMMARY

Calls for change in engineering education have been growing in recent decades<sup>[i,ii]</sup> but despite this, change in most institutions is typically incremental and on the relatively small scale of individual departments or modules. This paper considers a case study of a faculty-wide curriculum development project within a research-intensive environment and looks to describe how a large-scale interdisciplinary teaching framework was adopted, continues to evolve, and is changing the organisational culture, 5 years on from its inception.

### BACKGROUND / CONTEXT

Since 2012, the UCL Faculty of Engineering Science has been undergoing a major review and revision of all its undergraduate educational programmes. This has led to the Integrated Engineering Programme (IEP) being introduced across eight departments. The IEP teaching framework sought to provide students with interdisciplinary learning activities in the context of problem-based experiences, supported by instruction in transferable professional skills. The integrated activities were led by a newly hired small team of teaching-focused staff based in the faculty office. Typical of many change initiatives, the new cross-department curriculum was received with differing levels of enthusiasm and implemented with different levels of success in each department. This reflects both the culture and context of each department and often manifested itself in the level of engagement of key staff.

### AIM AND OBJECTIVES / RESEARCH QUESTION(S)

The challenges associated with change in higher education institutions are well rehearsed yet relatively few publications or case studies of the change process or the leadership strategies employed exist<sup>[iii]</sup>. This is despite widely held perception of effective leadership as the key element of sustainable change<sup>[iv]</sup>. The aim of this work is to explore the nature of change management within engineering education and its impact on teaching culture through the case study of a large-scale cross-department curriculum development programme within an Engineering faculty. The research question asks how strategies evolved in organisational and leadership approaches

from the initial phases of scoping and development, through to implementation and in the current task of ensuring that such a programme is sustainable for the long term.

## **RATIONALE**

Implementing change is difficult. This paper seeks to provide insights into the process and associated experiences, with the intention of opening up discussions with others also engaged in reviewing and revising their own programme curriculum. Although the context of each individual institution is different, we believe that elements of the change process that we implemented and the organisational response to it can provide useful insights to institutions wishing to achieve large scale change in engineering education pedagogies.

## **METHODOLOGICAL APPROACH**

This qualitative study uses a combination of autoethnographic analysis of the faculty team leading the development and implementation of the IEP teaching framework along with unstructured interviews conducted by a visiting member of staff with key team leads representing the departments involved. Analysed together they illuminate complementary viewpoints of the impact of the new faculty-wide teaching framework a result of the formal and informal processes and strategies adopted throughout the implementation of educational change.

## **KEY FINDINGS**

Although traditional literature on change typically focuses on aspects such as strategic planning, creating a clear mission and vision and developing a strong shared identity, we see that cultural change is equally important. We have identified a variety of responses to change adopted by different departments, which, for the purpose of this study can be considered as small organisations or cultures in themselves.

## **DISCUSSION**

The findings demonstrated that individual contexts and cultures faced by each of the departments have shaped the reactions to the imposed change. This required adaptive leadership which was able to negotiate separate implementations while still maintaining a strong focus on overall cohesion and shared goals. In the development of cultural change, concepts such as the foundation of communities of practice<sup>[v]</sup> emerge as vital in supporting change. This case study also demonstrated that the change processes needed to develop through a series of phases that evolved at different rates. Each phase requires different strategies and processes from the period of rapid, step-change, to the period of embedding, maintaining and supporting fundamental elements of the change as each department took on increased ownership of the programme and developed increased autonomy.



## CONCLUSIONS & RECOMMENDATIONS

This study has highlighted the challenges and responses to a curriculum development programme which had the aim of instigating and managing change across a variety of departmental curricula, cultures and identities in order to create a single harmonised educational approach. The driver for change was student-centred and aspirational. The aim for our students across the faculty is that they graduate from their degree programmes with similar professional skills, similar understandings about engineering design, context and impact, some shared identity, while also having expertise in very different technical fields, as well as an identification with their own discipline. This work has highlighted how the implementation of this ambition plays out differently depending on the inherent culture and existing teaching practices of the department in question. At the outset of the change programme, formal and directional leadership was important; as the IEP has become embedded in the undergraduate department-based degree programmes, informal processes became more important. The challenge remaining is to ensure that there is balance between strong top-down leadership and distributed leadership consisting of a less formal directive process, so that the maintenance of harmonised curriculum standards across eight departments is inclusive and effective.

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## A New Narrative for Engineering in UK Schools

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**KEYWORDS: People-Focused: Creativity: Narrative: Tribes**

### SUMMARY

Activity to attract sufficient numbers of students (particularly female students) into engineering and technical careers have relied heavily on promoting a narrow conception of the discipline through informal learning experiences. This conference paper draws on three research studies carried out by the Institution of Mechanical Engineers that consider the efficacy of a reliance, solely or largely on serendipitous exposure to engineering in the absence of a clear national educational narrative surrounding the subject. It is the first opportunity to bring together the findings of research that challenges the value of focusing mainly on 'inspiring' the next generation, in the absence of a better embedded discourse in school education. First, it considers how clustering of psychosocial features amongst UK teenagers generated five clearly defined values-based 'tribes' who expressed a greater or lesser affinity with the products and culture of engineering. Second, it draws on the findings of an expert seminar and national survey of key stakeholders of engineering skills to establish how perceptions and interest in engineering are affected by framing of engineering within the school experience of young people. The research explores the desirability of implementing a number of policy and practice options within formal compulsory education. It concludes that to appeal beyond its traditional audience, engineering in schools needs to be reconfigured as societally valued and people-focused. The third report seeks further insight into how engineering is experienced and conceptualised within schools, through two complementary pieces of work, mainly comprising an ethnographic approach to frame the narrative of engineering within 11 secondary schools in England, and a deliberative research study into the development of attitudes and ideas about engineering based around bespoke school debating competitions.

### BACKGROUND / CONTEXT

In 2015–16, motivated by the UK's engineering skills shortage, the Institution of Mechanical Engineers, carried out a research study, 'Big Ideas, The Future of Engineering in Schools' to explore how radical approaches in school-based education might challenge orthodoxy and produce a step change in the numbers and backgrounds of young people choosing engineering career. The research identified a range of factors contributing to the dearth of students opting for technical and

engineering career paths. In particular, the near-invisibility of engineering in schools was suggested to lead to poor understanding of what engineering entails and what engineers do.

'Big Ideas' drew on earlier work, *Five Tribes: Personalising Engineering Education*, which challenged the widely held narrative that engineering is a rarefied discipline appealing only to a narrow archetype. Subsequent research has shed light on the ecosystem at work within schools and the associated feasibility of implementing the actions and recommendations from these reports.

## RESEARCH QUESTION

*How should we be framing engineering in our education system so that the subject becomes an explicit aspect of a pupil's engineering experience?*

## METHODOLOGICAL APPROACH

**Study 1:** Qualitative pilot and UK-wide online survey of 1500 young people aged 12-19 adjusted to reflect population of all four home nations

**Study 2:** Online stakeholder survey (N=2500); seminar and follow-up online survey (N=40)

**Study 3:** Ethnographic study in 11 English secondary schools and online survey; Deliberative research activity and online survey

## KEY FINDINGS

There are five broad categories of adolescent attitudes to STEM within the nations of the UK; with each Tribe internally demonstrating shared values and beliefs, as well as similar attitudes to school, family and work.

- Technology appeals overall to some Tribes more than others but the greatest disparity is evident between the interests expressed by young women and men within the same Tribe
- Engineering should be positioned as a people-focused, problem-solving, socially beneficial discipline.
- The presence of engineering and the 'made world' should be made more explicit from primary school upwards.
- Access into engineering degree courses should be broadened through promoting more flexible entry requirements.

- All nations of the UK should offer a broad curriculum for all young people up to the age of 18.
- Engineering is largely absent from the secondary school narrative

## **DISCUSSION**

Too great an emphasis may have been made on presenting engineering as a set of job opportunities or a series of technical objects. For those STEM subjects appearing in the school curriculum, inspirational outreach engagement is the 'icing on the cake', whereas for engineering, it has become 'the cake itself'. Historical, socio-political and cultural factors contribute to a negative perception of engineering that clever marketing alone cannot change. Engineering must become more prominent in the education of all young people – not framed solely as a career or by its products, but as a methodology that humans employ to improve their lives. At the same time, changes are needed to the curriculum, assessment structure and timing of decision-making.

## **CONCLUSIONS & RECOMMENDATIONS**

With engineering having relatively little presence in the school classroom, these studies suggest that many students are ending up with a hazy understanding of engineering. They often fail to see its relevance to them as individuals, feel no connection with the discipline, and make early subject choices that can rule out engineering careers.

When prompted to reflect on engineering and its social and personal context, students *do then* perceive these links and have generally positive views of engineering. This is encouraging, suggesting that efforts to communicate a more coherent view of engineering as a socially beneficial, people-focused, problem-solving activity would be likely to strike a chord with student audiences. Such efforts could help to promote wider engineering and technological literacy, and potentially also encourage more young people to consider engineering or technology-related further study and careers – thereby helping to address the critical skills gap the country currently faces.

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## Engineering and Society: Embedding Active Service Learning in Undergraduate Curricula

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**KEYWORDS: Public Engagement, Outreach, Engineering Education, Science Education, Primary Teaching**

### SUMMARY

Undergraduate education incorporating active learning through education outreach presents a critical opportunity to influence future engineering teaching and practice capabilities. Engineering education outreach activities have been shown to have multiple benefits; increasing interest and engagement with science and engineering for school children, providing teachers with expert contributions to engineering subject knowledge, and developing professional generic skills for engineers such as communication and teamwork. A new module at the University of the West of England, Bristol (UWE), called Engineering and Society, paired 45 student engineers and 32 pre-service teachers to enact engineering outreach in primary schools, reaching over 900 children in 30 school classes. A pre and post longitudinal mixed methods design is being employed to measure change in attitudes and Education Outreach Self-Efficacy in student engineers; alongside attitudes, Teaching Engineering Self-Efficacy and Engineering Subject Knowledge Confidence in pre-service teachers. Previous pilot research indicates that highly significant improvements were noted in the pre-service teachers' confidence and self-efficacy; while both the teachers and engineers qualitatively described benefits arising from the paired peer mentor model.

### BACKGROUND / CONTEXT

Universities occupy a vital role in the community; thus undergraduate education incorporating active service learning provides opportunities to influence communities now and in the future (Direito et al. 2012). One example is engineering education outreach, where engineers take part in Science, Technology, Engineering and Mathematics (STEM) activities with schools and communities. These activities have been shown to increase children's interest and engagement with science and engineering (Molina-Gaudo et al. 2010; Stapleton et al. 2009) while also providing teachers with expert contributions to engineering and scientific subject knowledge (Laursen et al. 2007).

Attitudes at primary school in particular can influence later interest in STEM, especially for girls who develop their gender identity and consequently the appropriateness of STEM as a career before entering secondary school (Archer et al. 2013). This is



important for future STEM progression, as the way science is taught in primary and secondary schools has been identified as a contributing factor in the declining interest in STEM subjects at Higher Education level, which is critical for continuation into many STEM careers (EngineeringUK 2017). An inquiry-led, active learning approach can motivate learners and help them to achieve many of the end goals of science education (Madhuria et al. 2012). However, in order for such an approach to be successful, teachers need not only to have robust levels of subject knowledge but to also have confidence in their subject knowledge (Chue & Lee 2013). This highlights the importance of addressing and positively influencing pre-service teachers by cultivating positive dispositions and beliefs towards subjects such as science and engineering during their training, through opportunities to reflect on experience and practice in schools (Jung & Rhodes 2008; Flores & Day 2006).

Service learning through education outreach has also been found to benefit engineers themselves, enabling the development of generic skills such as communication and teamwork, required in professional environments (Direito et al. 2012; Pickering et al. 2004). In previous research, the authors demonstrated that positioning student engineers as 'experts' enables active learning, encouraging the consolidation and communication of engineering concepts to wider audiences such as children and teachers (Fogg-Rogers et al. 2016). Alongside this, working with the community enhances the employability of student engineers (Duffy et al. 2008), whilst also working towards professional codes such as the UK Standard for Professional Engineering Competence (UK-SPEC) or professional status awards such as Chartership.

## **AIM AND OBJECTIVES**

This project aimed to develop a new model of undergraduate education, integrating active learning through paired peer mentoring. Student engineers were paired with pre-service teachers to co-mentor each other to deliver hands-on inquiry-led science education to primary school children. The project objectives were to:

- Enable collaboration between staff from three interdisciplinary departments at UWE Bristol, alongside working with local schools, Education Continuing Professional Development (CPD) organisations, Informal Science Learning providers, and regional Engineering Industry and Professional Bodies.
- Enhance student employability by responding to demands from industry for ready and able graduates with: student engineers developing public engagement and generic skills for Professional Chartered Status; pre-service teachers developing Science, Technology, Engineering and Mathematics (STEM) subject knowledge and teaching confidence; and primary school children developing interest, enjoyment and positive attitudes to STEM subjects.
- Enrich primary school STEM capacity and provision by providing CPD for professional engineers undertaking outreach within the West of England region, taking account of gender and Black and Minority Ethnic role modelling and mentoring.

- Develop an undergraduate degree credit model which can be utilised within student degrees across the UK, meeting the needs for Engineering and Education professional body accreditation.

## **RATIONALE**

This project builds on pilot work undertaken from 2014-2016. The Children as Engineers report (Fogg-Rogers et al. 2015), and international peer-reviewed journal article (Fogg-Rogers et al. 2016) indicate that these small-scale models had significant benefits for volunteer participants, with student engineers gaining public engagement and other generic skills (important for Professional Chartered Recognition). The pre-service teachers showed highly significant improvements in STEM subject knowledge and teaching confidence/self-efficacy which is important for meaningful education outcomes in STEM subjects in primary schools, and the professional teachers reported being inspired to adopt a STEM approach to teaching. The children enjoyed the inquiry-led science education with expert engineers, which is important for developing children's aspiration and enthusiasm, especially girls, for future STEM subjects GCSE choices.

This project seeks to extend and evaluate this work into a sustainable degree-wide optional credit-bearing model for higher education students, which would enable it to be rolled out annually across UWE and nationally into other universities.

## **METHODOLOGICAL APPROACH**

Students (N=45) from engineering degrees at UWE have taken the newly developed 'Engineering and Society' module in 2017. The module has been designed to enhance engineers' communication skills and provide them with the evidence needed to complete the UK SPEC for Engineering Technicians. The engineering students are being assessed on their portfolio of evidence-based practice as well as a presentation of their learning about public engagement and engineering in society.

The engineering students were paired with 32 pre-service teachers taking an Initial Teacher Education degree. Training for the engineers was provided in public engagement, STEM and society, and inquiry-led science education, while training for the teachers was provided in the engineering design process and related STEM concepts. The paired students mentored each other to co-develop and deliver outreach interventions for local classes of primary school children. Ten primary schools took part in the project, reaching 900 children in 30 classes.

A pre and post longitudinal mixed methods design has been employed to measure changes in attitudes and Education Outreach Self-Efficacy in student engineers. The pre-service teachers were assessed for changes in their attitudes, Teaching Engineering Self-Efficacy and Engineering and Science Subject Knowledge Confidence. Impacts on the children are also evaluated.



## DISCUSSION

This new embedded model of service learning aims to provide real-world experience and opportunities for engineers and teachers. Engineers are being urged to undertake more public engagement in order to enhance perceptions of STEM careers (EngineeringUK 2017), and teachers are a very influential audience to work with. Indeed, research indicates that teacher professional development benefits the teachers, their school children, and the schools, and changes teachers' attitudes towards their teaching (Woolhouse & Cochrane 2009).

Peer coaching, such as that used within this project, may be useful for other engineering education courses, as it discourages practitioners from working in isolation and instead encourages active learning discussions (Van Driel et al. 2001). Engineering education outreach focussing on mentoring pre-service teachers is therefore valuable for engineers to influence societal attitudes and attainment in STEM, alongside improving their own generic skills for career development.

A toolkit from the pilot project (Fogg-Rogers et al. 2016) is available online (<http://eprints.uwe.ac.uk/26053/7/Web%20-%20UWE%202015%20Children%20as%20Engineers%20Paired%20Peer%20Mentors%20Final%20Report%20web%20version.pdf>), and further updates will be provided on the Science Communication Unit blog (<https://uwesciomm.wordpress.com/2017/09/11/engineering-in-society-new-module-for-engineering-citizenship/>)

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## Supporting Trailing & Failing Engineering Students: Timing and Awareness.

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**KEYWORDS: Changing Futures: Student Support: Failing: Trailing Subjects**

### SUMMARY

A continuation of the 'Changing Futures Project'<sup>[1]</sup> this work aims to directly tackle student failure in engineering education at Higher Education<sup>[2]</sup>. This stage of the project focuses on the experiences of 88 Engineering and Applied Science students who were classified as 'failing' in one or more modules during the Summer Term. A comparison of findings is made between the first stage (conducted during the Autumn Term) and the current findings of this research. Whilst the mental health findings of the initial stage of the project were present in the second stage, they were not as pronounced and the emphasis for the students appeared to have shifted to practical concerns and a need for information about the 'next steps'. All students were offered individual support, including signposting to the support facilities available to them. The initial findings surrounding the students' experiences indicate that many students do not initiate contact with the university and lack awareness of the channels of support and communication available to them. To counter this finding, a series of informative workshops are being devised for students to take place during the 2017-18 academic year.

### BACKGROUND / CONTEXT

Retention and academic success are topics which are frequently discussed within UK Higher Education, with an ongoing debate about the factors underpinning student attrition<sup>[3,4,5,6]</sup>. Whilst retention rates across the whole of the Higher Education sector are the topic of debate, the lack of recruitment into engineering course combined with the percentage of students failing to complete engineering programmes of study in the UK is of national concern<sup>[2, 7]</sup>.

### AIM AND OBJECTIVES

The original project set out "to directly tackle the issue of attrition and student failure in engineering and applied science at Gosta University" [1] and this aim is continued through the current work.



The objectives of the study are:

- Using data-analytics, identify students at risk of attrition.
- Investigate students' perceptions of the reasons behind their failure.
- Investigate students' perceptions of the support that they feel they require at this stage in their academic journey.

## **RATIONALE**

This study is designed to improve the provision of student support offered to engineering and applied science students. The ultimate aim is to reduce instances of student failure within the cohort. Whilst the wellbeing of the students and their academic and professional success is of utmost importance, the financial consequences of attrition are of concern for universities.

## **METHODOLOGICAL APPROACH**

In total, 494 engineering and applied science students were identified as being 'at risk' using the definition provided by Andrews and Clark<sup>[1]</sup>. Validation of the sample occurred via the process of cross checking the data against student records. During this analysis, a note was made of:

- Relevant demographic information
- Programme of study enrolled on
- Modules trailed.

Due to the volume of the sample, an email was prepared and sent to each student, addressed to them individually. The email asked the students to reflect on three questions:

- How are you?
- Did anything happen last year that may have affected your studies and that the university might not be aware of?
- Is there anything that you need from the university right now to help you?

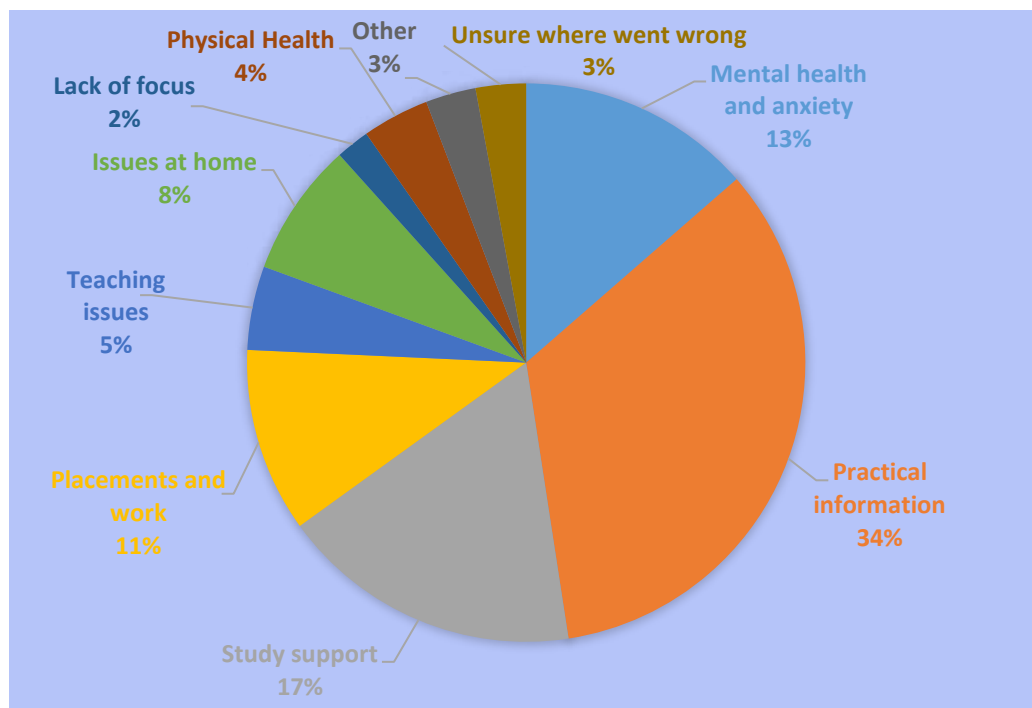
At the time of writing, responses have been received from 88 students. Five students requested a meeting with the researcher (two of these students did meet with the researcher) and the remaining 83 responses were received via email. Thematic coding was carried out and categories of response were identified for the overall sample.

The students who responded were offered a revision support document or were given signposting to support services, such as the university wellbeing team, the Learning Development Centre, a more senior tutor, Programme Director, or their personal tutor. The support offered aimed to encourage and foster personal responsibility and independent learning.

## KEY FINDINGS

The initial findings concentrate on the types of problems which the students highlighted in their responses. The feedback, concerns, and questions which were received from the sample were coded into themes, the frequency with which each of these themes occurred across the sample is given in Figure 1. The main themes which the students mentioned in their emails were practical information, study support, and mental health or anxiety issues. These three areas are discussed in more detail below.

**Figure 1: Student Concerns**



### Study Support

This theme encompasses a range of student concerns and queries, ranging from very focuses questions regarding particular modules or pieces of coursework, to broader issues of revision. The majority of concerns within this theme were focused on specific modules, again reflecting the students focus on the referred exams.

### Mental Health and Anxiety

A number of individuals spoke about mental health and anxiety issues which they had faced during the year or were currently dealing with. A number of cases

presented cause for concern for the researchers and students were signposted to support services and were advised to talk to their personal tutors about their situation if they had not already.

### **Practical Information**

The majority of student concerns were focused on the practical issues of the referred exam period, at the time that the initial emails were sent to the students exam timetable information was not available, this along with other practical information requests and concerns (such as library opening times, concerns regarding travel from overseas and securing time off work), made up the majority of the initial responses received.

### **DISCUSSION**

The responses received from the students in the second phase of this study differed from those which were received during the first phase<sup>[1]</sup>, where mental health was a dominant theme. The most significant difference between the two stages is considered to be the timing of the support intervention; the first phase approached students in the Autumn term and the second phase in the Summer term. A comparison of the findings suggests a shift in the focus of the students from self-reflection (why things went wrong for the students and how they could be improved) onto the imminent referred exam period (how to get through the exams). This move towards seeking practical help and focused study support, may also be due to the method of enquiry used by the researcher. In this first phase the students were invited to speak to the researcher face-to-face or on the phone, due to the magnitude of students in the second phase this was logistically impossible and so contact was made via email; a form of data collection which is less personal.

This change in student focus may also have implications for the outcomes of the support offered. Where support was offered during the Autumn term, the students had time to develop and implement study skills and techniques for dealing with issues during the following teaching period. Where support is offered during the Summer term the students have limited time to use and implement the support offered prior to the referred exam period, which determines their progression at university. It is predicted that this will be evident in the progression rates of trailing students after the referred exam period. This data is currently being analysed.

The findings presented here also indicate two additional areas which are worthy of discussion at this stage, information dissemination and requesting support.

### **Information Dissemination**

Many of the responses from the students were questions whose answers are available on the university website, or in university documentation, for example questions regarding university library opening hours, ECAP procedures, coursework submission, and capping of marks. This highlights a lack of awareness of university procedures

and how to access information was also evident from the questions which were asked by the students. Whether this is reflective of the students own motivation or a deficiency in the dissemination of information is unclear at this stage.

### **Requesting Support**

From the responses it is clear that some students struggle to make contact with the university, the responses that were received indicated that only a small number of the students had already spoken to someone at the university before replying to the researcher. The nature of the concerns that students presented, and the form that these took, highlights the lack of awareness of the channels of communication that exist at the university.

## **CONCLUSIONS & RECOMMENDATIONS**

The most significant finding of this project to date is the importance of the timing at which we provide information to students and the form in which we give this information. The practical concerns that students have regarding resitting exams may be causing additional stress and anxiety at an already demanding time. The limited time which the students have between support offered in July and the referred exam period in August may have an impact on the ability of support to be effective if complex issues are presented by students.

The findings have implications for the wider Higher Education Sector in terms of how students who 'fail' are supported. The following recommendations are made:

### **Recommendations for Institutions**

1. Put into place channels of communication between the university and students that are highly visible, easily accessible and readily available - thereby encouraging students to make contact and ask for help when needed.
2. Increase student awareness of university regulations and procedures: Most students don't access the regulations until they find themselves 'falling foul' of them. It would be beneficial to all parties if students were informed right from the onset what happens when they fail, how their final degree award is calculated etc.
3. Attempts should be made by a relevant academic to personally contact individual students who have failed modules and check that they know when and how they will be re-examined.
4. Clear information should be provided to students who have failed modules to inform them of this and the process which follows.

## **Recommendations for Students:**

1. Individual Students should seek help at the appropriate time by contacting their Personal Tutor, Programme Manager or Head of Department. At the very least students needing help are urged to contact the Student's Union Support Services.
2. The Students Union could consider offering Mental Health Awareness to students.

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## Putting Projects Into a Societal Context

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**KEYWORDS: Undergraduate Projects, Impact, Engineering, Design Build Test, Non-Technical**

### SUMMARY

This is work in progress – indeed in its early stages. We have designed a number of questions to encourage students to consider – while conducting their projects – the societal and pedagogic context of their work. These questions will be trialled with proto-students in advance of the admission of students to NMiTE in 2020. The results will inform the design of support for students during their project work.

### BACKGROUND / CONTEXT

Projects are a feature of almost every undergraduate engineering programme, although the word “project” covers a multitude of different activities: Projects can be carried out alone or in teams; they can arise from undergraduate students themselves, research labs, industry or the fertile mind of their supervisor; they can last a year or a week; they can be focused on a specific engineering topic or they can be (in the terminology of the USA) capstone; they can result in an artefact, a report or a piece of software; they can address a closed or a wicked<sup>1</sup> problem. There is a huge literature relating to projects, although because of the diversity outlined above, comparison or translation of results is not always easy (see for example the hundreds of papers in the proceedings of the twelve CDIO international conferences [1]). I will leave aside the definition of a project and also the sets of wicked problems associated with comparability, assessment, supervisor involvement and team working.

This work was stimulated by a meta-analysis by Passow [2, 3, 4] which shows that the least-highly regarded aspect of professional engineering competence is “contemporary issues and understanding the impact of one’s work”. Why? Emerging curricula (eg, but not only, NMiTE [5]) are increasingly emphasising this aspect of engineering and are also proposing a substantially increased amount of project work. In such new engineering programmes student attitudes to the world around them and the actual and potential impact of their work (on themselves and others) will be important both to graduate success and to retention.

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<sup>1</sup> A **wicked problem** is often defined as a *problem* that is difficult or impossible to solve because of incomplete, contradictory, and changing requirements that are often difficult to recognize. For our purposes it is a difficult problem with no right answer!

## AIM AND OBJECTIVES

The aims of the study are firstly to determine whether students can, themselves, assess the significance and potential impact of their project work and secondly to identify areas where they may need support in this task.

## RATIONALE

The study is necessary in order to inform the planning and development of project-based modules. In the proposed NMiTE curriculum [5] such projects will occupy a major fraction of the students' time and it is important that an appropriate amount of support is offered. The results of this study will inform decisions on the extent and nature of this support.

## METHODOLOGICAL APPROACH

Two small year-cohorts of unregistered proto-students<sup>2</sup>, in 2018 and 2019, will be trialling the 25 or so projects which will form a great part of the proposed initial NMiTE curriculum from 2020. In each prototype project five or more of the following nine non-technical questions will be asked:

1. \*Why are you doing this? (learning, societal need, technical need, timely ...)
2. How many? (market analysis, scaling up ...)
3. What does it cost? (materials, costings, manufacturing methods, transport ...)
4. Who will pay? (individuals, government, business, taxation ...)
5. What is the likely impact? (on the environment, on depletion of resources, on society, health, aesthetics, noise ...)
6. What are the risks, and how might they be mitigated? (associated with the project itself, the product ...)
7. What happens afterwards? (end-of-life disposal, recycling, re-use, what replaces, changes in society ...)
8. Which language/country? (target country of use, language of reporting ...) NB: students will be encouraged to submit a minority of reports in a second language.
9. \*How could the project outcome be improved? (better, cheaper, lower/higher impact, lighter ...)

The questions have been designed to encourage the students to consider several of the aspects of an engineer's work which are not heavily technical, including the impact and societal context of the work. Each question will be tackled by at least one student in each team, who will be expected to produce a significant report on the question (representing several days' work). Questions 1 and 9 will always be asked, while the selection of a further two or three will depend on the nature of the project. We will

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<sup>2</sup> A proto-student is a person (probably but not necessarily young) who is acting as a student for testing purposes without being registered on a programme. Such proto-students might, for instance, be working during a gap year.

assess, by questionnaire and focus groups among both staff and the proto-students, the extent to which these questions presented either difficulty or interest (or both or neither!) to the students.

## DISCUSSION

We expect to discover the areas where students are able to reflect usefully on the context of their studies without much further guidance, and also those areas where advice and guidance is clearly necessary. This will help us to design appropriate support for these more challenging areas. We expect to conduct the survey with about 75 proto-students in 2018 and 2019 and deploy its findings in time for the first full cohort of students arriving in 2020.

## CONCLUSIONS & RECOMMENDATIONS

It is somewhat surprising that our approach does not appear to have been used elsewhere in engineering education. The author would be delighted to receive details of examples he has missed!

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## The Final Word: Concluding Remarks

These proceedings of the 5<sup>th</sup> symposium of the UK & IE Engineering Education Network give the opportunity to reflect upon the progress the Network has made and consider what the future may hold for the Network and engineering education in general.

This symposium has seen the continued growth in delegate numbers, for the first time exceeding 100, in addition to having a programme extending over two days. We have welcomed delegates from HEIs not previously taking part in EER activity and continue to welcome friends from beyond the UK and Ireland. The substantial support of the Royal Academy of Engineering in hosting the physical event also extends to our virtual presence where the proceedings of the previous symposia can be found ([www.hefocus.raeng.org.uk/eern\\_home](http://www.hefocus.raeng.org.uk/eern_home)).

At the symposium, there has been shown a growing confidence within the Network and an interest in an extending range of methodological approaches is broadening the themes being examined. This is also enhanced by continued collaborations within the Network and with educational researchers from other disciplines, particularly the Social Sciences. It is important to have motivational factors whilst there are still barriers to recognition, for example, of where EER sits for many in relation to drivers such as REF and even in the shorter term TEF. The road to maturity of EER will clearly have to address the evidencing of impact within the engineering sub-disciplines and across all HEIs.

So what are the emerging themes which may be seen as becoming the “grand challenges” of EER for the next decade? This symposium has through the key-note presentations and workshop debate scanned the engineering education horizon, if unhindered by the journey where would we like to be at our 15<sup>th</sup> annual symposium?

Consideration of the response of engineering to the needs of Society was the subject of several presentations, with professionalism and ethical practice as an extension of more direct graduate attributes being one overarching theme offering student motivation through the opportunity to contextualise and add authenticity to learning activities.

The entry and exit of students was another clear theme, particularly the attributes that graduates need to meet industry’s expectations. A long running theme has been the need to make engineering education more accessible to a diverse and gender balanced student cohort – overcoming negative connotations in early years education but also looking for more creative approaches to changing choice of subjects on entry to HE.

If any one single theme stood out during the presentations and discussions it was a focus on students ‘doing’ rather than ‘knowing’, supporting the desired graduate

attributes of observation, reasoning and creativity. This demonstrates a growing realignment of thinking about how the information age is reshaping education and employment. Knowledge, now so abundant, cannot on its own create new solutions to global issues. It is our graduates who will identify opportunities and create solutions through 'good use' of selected knowledge for the benefit of Society. Inspirational engineers, for example; Telford, Watt, Brunel, Marconi, Whittle are known for their practical contributions to transport, motive power and communication rather than expressions of their knowledge.

The conservative approach to engineering HE resulting from factors such as the REF, the TEF and newspaper league tables perpetuates the status quo despite acknowledging lost opportunities in diversity and gender. The next few years will see if EER can play an active part in supporting change within academic departments through establishing a profile for 'research of teaching' within the recent growing trend of stressing 'research for teaching' taking place under the potentially confusing name of 'research into teaching'.

It has been often said that current engineering students will need the ability to undertake jobs that have yet to be invented, therefore their awareness and ability to extend their learning throughout their working lives should be explicitly underpinned within their current learning activities. Whilst current Network activity is beginning to address this area it will have to start to challenge orthodoxies within engineering HE, for example much current programme design seeks alignment with external benchmarks and recognition frameworks, for example UK-SPEC and ABET.

This may seem to be suggesting a need for change of earthquake magnitude with associated risk, but then the risk of no change is that we only extend the growing shortage of suitably minded graduates entering industry. So, what would the magnitude of such a change be?

One approach often employed in problem solving is to look at the problem differently. When this is applied to the conventional HE engineering programme and its underpinning frameworks it may be suggested that it is not omission which needs to be addressed but precedence, effectively we currently have all the right stuff but in the wrong order. The symposium and these proceedings have drawn attention to the way engineers think, the value to their practice and esteem of what they are able to do and its positive impact upon Society. Therefore a concluding thought would be that a general reversal of the order, which suggests hierarchy, in which the defining criteria of degree programmes are evaluated would result in the context of engineering skills and practice preceding its underpinning maths and science – a shift in emphasis of learning process to ability being supported by knowledge.

*"The aim of education is not to transfer knowledge; it is to guide the learning process, to equip the learner with the methods of research. It is not the piecemeal merchandising of information; it is to enable the acquisition of the methods for learning on one's own; it is the provision of keys to unlock the vault of knowledge. Rather than encouraging*

*students to appropriate the intellectual treasures uncovered by others, we should enable them to undertake on their own the process of discovery and invention."* Tsunesaburo Makiguchi.

From, 'Complete Works of Tsunesaburo Makiguchi', (in Japanese) Daisan Bunmeisha, Vol 6. 1934,  
<http://www.tmakiguchi.org/resources/selected/pedagogy.html>

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# APPENDIX 1:

## The UK & Ireland Engineering Education Research Network: Further Information

With its origins in a partnership between the HEA Engineering Education Centre at Loughborough University and Aston University, the UK EER Special Interest Group (SIG) was founded in 2008. The first National EER SIG Day Conference took place in 2012 at Loughborough University. Since then, the community has grown. Changing its focus from that of a 'group' to a 'network' and bringing Ireland into the fold, the Network now has well over 100 members from across the UK and Ireland; with other members being drawn from Europe and Australia.

Brought together by a passion and belief that Engineering Education should be unpinned by sound pedagogical evidence, the EER Community continues to grow. The 5<sup>th</sup> Annual Symposium of the Network represented a turning point for our community. Together we now represent numerous perspectives, interests and disciplines. A Newer Researchers SIG is soon to be launched under the auspices of the Network where there is plenty of room for emergent groups to be hosted and views to be heard.

The Network is honoured that the Royal Academy of Engineering provides the 'home' for our website which may be found at: <https://hefocus.raeng.org.uk/eern-home/>

### Joining the Network

Membership of the Network is open to all colleagues with an interest in Engineering Education Research. Primarily for the UK and Irish communities, members from elsewhere are welcomed.

Membership is free of charge and open to academic, professional support staff, postgraduate students, professional body members and representatives as well as any colleagues working in industry.

To become a member please email Dr Jane Andrews [j.e.andrews@aston.ac.uk](mailto:j.e.andrews@aston.ac.uk)

**2018 Spring Colloquium:** Will be hosted at the University of Northumbria on 10<sup>th</sup> May from 1300-1900 hours. The subject of the Colloquium will be 'Pre-University Engineering Education: Does it exist and if so, is it worth it?'

**2018 Annual Symposium:** Will be hosted at the University of Portsmouth on 1<sup>st</sup> and 2<sup>nd</sup> of November. This year's Symposium will continue the theme of 'Challenging the Status Quo' and will ask 'What next for Engineering Education?'





With thanks to Rhys Morgan and  
The Royal Academy of Engineering,  
London.