ENGINEERING ENGINEERING
A PROVOCATION

PROFESSOR KEL FIDLER CEng HonFIET FREng

JUNE 2021

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ACKNOWLEDGEMENTS

What follows are the thoughts and opinions of the author. They are based on published data and reports and I have given extensive references to support these.

I acknowledge the very helpful and much appreciated financial support of the Royal Academy of Engineering in obtaining data from HESA used to support the arguments that I have deployed. Also acknowledged and thanked are the many people (too numerous to mention) who read my various proofs and provided useful comments.

Finally, I thank my dear wife Nadine for her support and forbearance during the times I disappeared into my study, or into deep thoughts – even during periods in our motorhome in various parts of the country when we were supposed to be on holiday!

Kel Fidler
Terrington, North Yorkshire
October 2020

ABOUT THE AUTHOR

Prof Kel Fidler is a Chartered Engineer and a Fellow of the Royal Academy of Engineering. He graduated with a BSc and PhD in Electrical Engineering from Durham and Newcastle Universities respectively. He worked at Essex, the Open and York Universities being Head of Engineering Departments in each. He was also Pro-Vice Chancellor and Deputy Vice Chancellor at York, and then went on to be Vice-Chancellor and Chief Executive of Northumbria University. Active in retirement, he has been, inter alia, Advisor to the Food and Drinks Federation for a new Degree in Food Engineering at Sheffield Hallam University; Advisor to NMiTE (on the course structure and philosophy of a proposed new Engineering University in Hereford) from 2014-18, Member of the Royal Academy of Engineering Education and Skills Committee, Member of the Board of Arden University, Founding Chair of the Industrial Advisory Committee at Huddersfield University, and Member of the Ethics Committee at the University of York. He continues to be a member of the External Advisory Committee in Engineering at York.

In a parallel voluntary career with the Engineering Profession, amongst many other things Kel was Chairman IEE Professional Group E10 (Circuit Theory and Design); of the IEE Accreditation Committee; and of DABCE (the Degree Accreditation Board for Chartered Engineers that became EAB).

He was Chairman of the Registration Standards Committee of the Engineering Council and led the groups that produced UK-SPEC and AHEP. He then served as Chairman of the Engineering Council for two three-year terms during which he was also ex-officio a Board member of ETB/EngineeringUK. He also acted as a consultant Lead Assessor for BSI in relation to BS5750/ISO9000 for the Electronics Industry. In recent times he was a member of the IET Fellows Standing Panel and led a review of the IET's Fellowship award process. As a member of the IET Education and Skills Policy Panel, he instigated an initiative that delivered a Conference on New Approaches to Engineering Higher Education in 2017. He is currently Deputy Chair of the RAEng Visiting Professors Management Group.

Kel is a Fellow of the Royal Academy of Engineering and an Honorary Fellow of the IET. He holds Honorary Degrees from the Universities of York, Northumbria and Huddersfield.

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EXECUTIVE SUMMARY

The UK education system cannot produce enough engineers – and in particular graduate engineers – to meet demand. There is a profound shortage of engineering skills. Commentators have suggested at least a doubling in numbers is required to address this shortfall. Engineering graduate numbers have been trending slowly upward in recent times, nevertheless such a doubling would take at least 40 years. In this report, I have highlighted key areas of concern – detailing the issues that are frustrating attempts to solve this 'skills crisis' in Engineering higher education as well as recommending solutions. In summary:

- The huge number of initiatives and interventions aimed at increasing both the total number and the diversity of engineering graduates have largely proved ineffective.
- The proportion of overall UK domiciled higher education graduates that qualify in the JACS Engineering & Technology (E&T) Subject has stubbornly stuck at around 5% over a 14-year period (2005/6 to 2018/9).
- There is an urgent need to reverse the severe downward trends in the popularity of degree programmes in Electrical & Electronic Engineering, and Production & Manufacturing Engineering – both subject areas of great economic importance.
- The skills crisis is unlikely to be resolved by focussing more effort on outreach and intervention strategies in schools and colleges. There is a need for different approaches to improve the appeal of E&T university programmes.
- Examination of graduate numbers across all 19 JACS Subject areas over the period 2005-18 reveals quite dynamic behaviour. There is no reason for Engineering & Technology to remain static, given the right recruitment and learning methodologies.
- Whilst the number of international student graduates on E&T programmes has increased over the period examined, market share of the total number of international graduates has fallen. Corrective action is required.
- Attempts to get more women into engineering have been even more disappointing. Women outnumber men in higher education, yet only 15% of E&T graduates are women – again a number that has changed little over at least the past 14 years, illustrating the gross under-representation of women in engineering. New thinking is required – including addressing the disjunction between the proportion of women that engage with Design & Technology GCE Advanced Levels and those that show an interest in engineering degrees.
- Over-stressing the need for a background in Science (particularly Physics) and Maths does a disservice to attempts to interest young people in engineering. Engineering higher education should not be seen as the accumulation of knowledge (typified by courses in science and maths leading to engineering topics), but as engagement with the 'process of engineering' – embracing creativity, design and innovation as the main activities in taking a customer requirement through to practical realisation.
- There is often a disjunction between employers' needs and higher education provision.
- To attract more young people into the profession we need a radical reassessment of our Engineering higher education programmes alongside a radical reassessment of the measures that need to be taken to assure their delivery through the AHEP Standard and Accreditation.
- A concerted effort is needed to promote a better understanding of what engineering is and the roles which engineering/professional engineers play in benefitting society through the solutions they design and make.

PREFACE

FROM PROFESSOR COLIN TURNER, President of the Engineering Professors' Council

Few can boast so rare a pedigree of accomplishments in Engineering higher education in the UK as Professor Kel Fidler. And, having scaled the heights, there are few people better placed to take an overview of whether we're doing well enough at what really matters.

As this polemical paper report makes clear, all is not roses in the garden of Engineering. We have the interlinked challenges of too little diversity among engineers and too few engineers to meet the social, environmental and economic needs of the future.

Some of our best efforts to resolve these challenges have not yet created the change we want to see, and so it is right to reflect on what more – or what else – we might do.

As anyone who knows him would expect, Kel has not held back in this 'provocation'. Some people may disagree with his diagnosis of the problems and many will no doubt disagree with some of his proposed solutions, but that, surely, is the point of a provocation?

As the voice of Engineering academics, we shall hold our peace for the time being, but we wholeheartedly welcome a no-holds-barred debate about what we can do better and, as consensus emerges, we will do our best to support and disseminate positive change. Kel's contribution is intended to get the stone rolling down the mountain and, for that, we are grateful to him and we are delighted to encourage the ongoing discussion.

FROM PROFESSOR KEL FIDLER

The UK needs more engineers, and in particular more graduate engineers – indeed commentators have suggested that the number should be at least doubled. Although the number of graduate engineers has been trending upward in recent times, to get that doubling would take at least 40 years.

A huge number of initiatives in schools have been introduced in past years to try to accelerate the number of engineering graduates, but to no avail – the *proportion* of overall graduates that qualify in Engineering & Technology subjects has stubbornly stuck at around 5% for at least 14 years – so no significant increases have resulted from those initiatives. Other subjects have had successes and misfortunes over the years – significantly Computer Science had a massive downturn in graduates at the beginning of the last decade, but since then, like E&T, it too has flattened.

Attempts to get more women into engineering have been even more disappointing. Although women outnumber men in higher education, only some 15% of E&T graduates are women – again a number that has little changed over the past 13 years.

It is against this background that this document is now presented as a provocation – a disruptive think piece – based, where possible, on hard facts. It investigates the reasons why we are where we are, and the possible ways out of the difficulty. I explore the ubiquity and importance of engineering in all our lives, and yet society's lack of understanding of the activity; I talk about the lack of understanding of engineering *within* Engineering higher education – for example, the belief that Engineering is the last part of a continuum through Science and Mathematics, which only students well versed in science and maths can enjoy, and is part of 'applied science'. There is mention of the disservice that the media give to engineering – either ignoring it or attributing it to science.

I then turn to examine how we have arrived at the current situation following the seminal Merriman and Finniston reports of 40 years ago and the development of accreditation, the BEng and the MEng – and our apparent failure to meet the requirements of accreditation and industry in our higher education institutions, despite the work of the Engineering Council and the creation of AHEP and UKSPEC.

I suggest ways that we can capture the enthusiasm, passion, versatility and vitality of young people with a variety of backgrounds and interests, and suggest adoption of the new approaches to Engineering higher education that are currently gaining the interests of universities and employers around the globe – providing an active learning engineering education that embraces 'creativity, design, and innovation' in a 'problem-based learning' (PBL) format, using all the latest techniques in 'flipped classrooms', 'lean learning' and 'content mastery'.

And much else besides.

In short, I humbly submit my thoughts to you as a way of 'engineering engineering' in higher education for the better good of the UK and beyond.

Kel Fidler
Terrington, North Yorkshire, October 2020

THE PROBLEM

It will not have escaped the attention of anyone with even the slightest interest in engineering that the UK needs more engineers – at all levels. Whether they are engineering craftspeople, engineering technicians, or professional engineers, we need more – and they need to be good ones.

A recent edition of EngineeringUK's excellent regular report *The State of Engineering*[1] makes this quite clear. There is an annual demand for 124,000 engineers and technicians with essential engineering skills across the economy. Despite the supply of talent coming through the education pipeline, there is an anticipated annual shortfall of between 37,000 and 59,000 engineering graduates and technicians to fill core engineering roles going forward. For engineering graduates specifically, if all of them gained employment in engineering roles, the shortfall is forecast to be 22,000 each year. In reality, since many do not, the shortfall is significantly higher.

It would not be going too far to call this shortfall a skills crisis and much effort and resource has been (and continues to be) expended to solve the problem it presents and so ensure a successful and sustainable economy in the UK.

So how are we doing? First, we have been *doing* things for some time. Back in the 1970s, Essex University's Department of Electrical Engineering Science hosted the then National Electronics Council 'Link Scheme' that sought to link schools with local engineering industry in an attempt to enhance young people's understanding and interest in engineering. The Scheme was to be one of the first of numerous so-called 'outreach' and 'intervention' activities which have developed particularly for primary and secondary schoolchildren. Indeed, of all such activities in schools and colleges, it would be easy to believe that engineering is the leader – and no wonder that some schools are reeling in confusion over how to engage and with whom? In a 2016 report[2] by the Royal Academy of Engineering, it was stated that "The Academy has undertaken a detailed mapping of the […] education landscape and has identified over 600 organisations that are in some way involved in supporting engineering education". This reflects a huge number of initiatives – although given that the total number of primary and secondary school pupils in the UK is around ten million, such a number is perhaps not too surprising. Reaching out to all school pupils is a massive undertaking. Just how successful are all these initiatives?

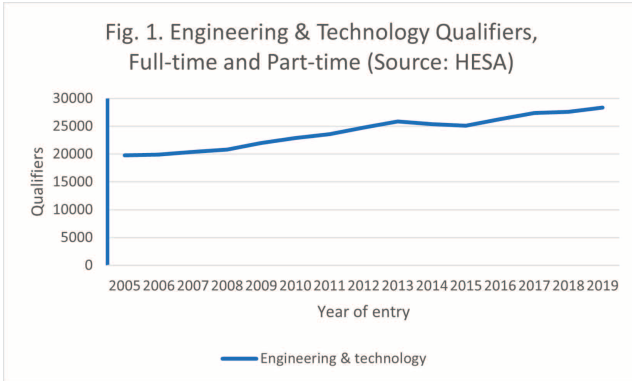

Fig. 1. E&T qualifiers – full-time and part-time (Data source: HESA for all graphs unless otherwise stated).

Fig. 1. Shows the numbers of higher education full-time and part-time male and female first-degree qualifiers (i.e. students who graduated)[3] in the JACS[4] subject area of Engineering & Technology (E&T) in the UK in each academic year indicated, and applies to all domiciles (UK, EU and other international).[5] There is a comforting apparent rise over years 2005 to 2019 from around 20,000 to 27,600.

However, with an average increase of some 550 graduating each year, meeting the current shortfall of 22,000 or more graduates mentioned above would take at least some 40 years to achieve.

There are moreover several further discomforting features of this result. It is instructive to see for comparison how overall qualifier numbers have changed over the period (in other words, in all subjects of study). This is shown in Fig. 2.

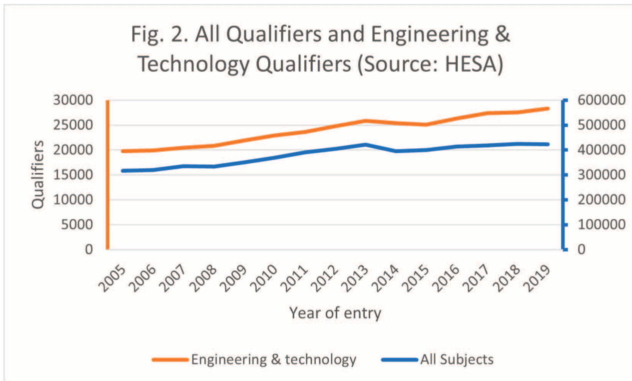

Fig. 2. All qualifiers and E&T qualifiers.

1 www.engineeringuk.com/research/engineering-uk-report/
2 www.raeng.org.uk/publications/reports/uk-stem-education-landscape
3 In past reports, UCAS data on numbers of engineering applications or applicants has been considered to indicate the dynamics of engineering undergraduate student recruitment. Not all applicants use the full permissible number of applications (nor only apply for engineering), however, and not all apply through UCAS. This rather blurs the significance of resulting analyses – as does the Clearing system and changes in presentation of the statistics by UCAS. Using qualifiers (number of graduates) on the other hand removes such problems since it simply portrays those students that have successfully graduated and are ready for the job market (although of course not necessarily in engineering) or further study.
4 JACS (the Joint Academic Coding System) is a way of classifying academic subjects and modules used by HESA (The Higher Education Statistics Agency) and UCAS (Universities and Colleges Admissions Service).
5 For clarity and brevity, these domicile descriptors correspond respectively to HESA's terms of 'UK, other European Union and other non-European Union'.

The two traces are similar in form suggesting that the increase (or decrease) in E&T qualifiers might simply be a result of scaling – since if there are more or fewer students in the higher education system each year then it would not be surprising for there to be proportionately more or fewer E&T students and qualifiers respectively – a phenomenon of scaling, mind, that many commentators incorrectly claim to be a result of particular recruitment initiatives.

However, before considering this, there is a further point that needs to be clarified. The E&T qualifiers shown are *for all domiciles*. Clearly, in considering the dynamics of the UK engineering workforce in the future and the effects of UK student recruitment initiatives, we should separate out the UK domiciles from the EU and the international, since the UK employment prospects for EU and other international students post-Brexit are by no means certain.

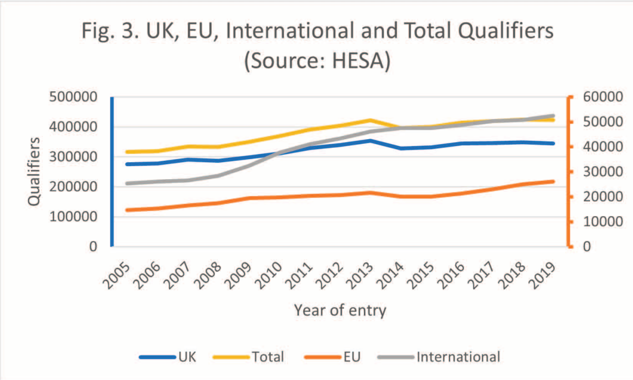

Fig. 3. The number of overall qualifiers which incorporates those from the UK and, using the right-hand scale, EU and international.

This is evidence that UK higher education is highly regarded around the world, since the number of international qualifiers has doubled as has (almost) the number of EU qualifiers over the period (N.B. the right-hand axis scale applies in both these latter cases).

Having separated out the domiciles, we can now examine the trends in E&T qualifiers from the three domicile groups using HESA data. Fig. 4. Shows the results for international qualifiers.

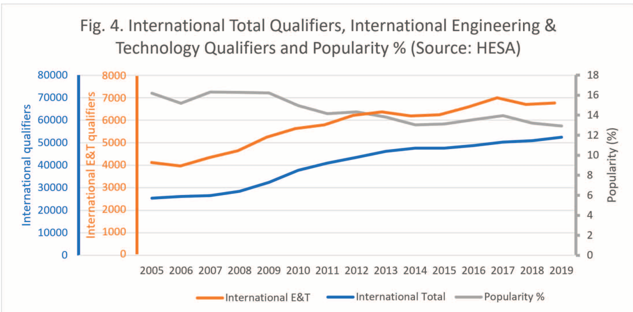

Fig. 4. International total qualifiers, international E&T qualifiers and, using the right-hand scale, percentage popularity.

The graph shows the total international qualifiers numbers, the number of international E&T qualifiers, and the 'popularity' of E&T– in other words the proportion (as a percentage) of the total international qualifiers who qualified in E&T each year. This 'popularity' could also be interpreted as the E&T 'market share' of the international student market. There is a comforting increase in international numbers over the period; nevertheless, the graph brings evidence through the popularity curve that E&T's market share of international qualifiers has in fact fallen, some 3% having been lost. international student numbers are important[6] financially to UK universities and their departments – so the significance of not being complacent by judging qualifiers numbers alone is manifest.

FINDING 1
Whilst the number of international students graduating on Engineering & Technology programmes has increased over the 14-year period from 2005/6 to 2018/9, the E&T market share of the total number of international graduates has fallen.

Next, the results for EU qualifiers are shown in Fig. 5.

The effect of Brexit on the future of students from the EU casts some doubt on the utility of this graph in considering the future. However, we clearly see that an overall rise in EU total qualifiers over the period belies the fact that EU student market share for E&T has steadily decreased, by 4% (from 12% to 8%).

Finally, we come to UK domiciled qualifiers in Fig. 6.

This shows a staggering result for popularity – which merits spelling out: **the proportion of the total UK domiciled qualifiers that have qualified with Engineering and Technology First Degrees each year from 2005/6 to 2018/19 has been almost constant at about 5%.** In fact, the average over the period is 5.1% with a standard deviation of 0.2%. This would seem to confirm the impression that as overall UK-domiciled higher education student numbers and hence qualifiers have bumped up and down according to the vagaries of demographics, career choices, fee increases and student number cap removal, E&T qualifier numbers have scaled in alignment.

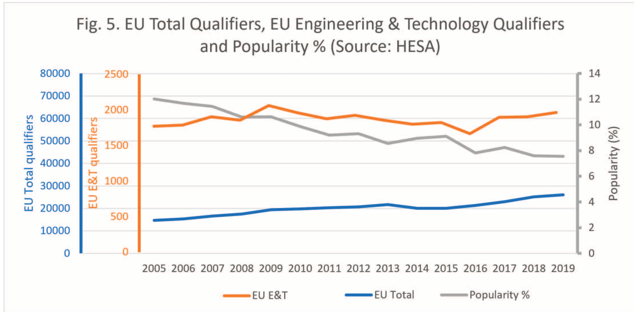

Fig. 5. EU total qualifiers, EU E&T qualifiers and, using the right-hand scale, percentage popularity.

6 International students have become a key source of funding for UK universities, and provide a significant contribution to the UK economy through tuition fees, living expenses and associated income such as from parents' visits to the UK.

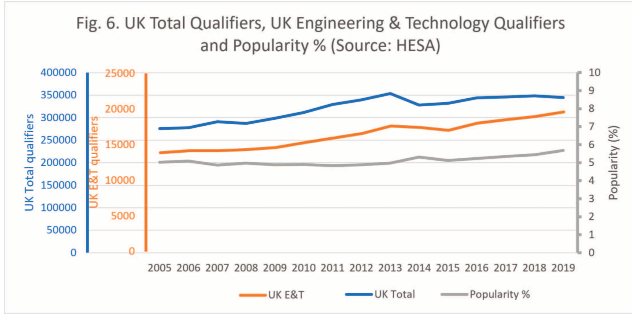

Fig. 6. UK total qualifiers and, using the right-hand scale, percentage popularity.

The inevitable conclusion is that despite the huge number of outreach and intervention activities in schools and colleges, they have had *no significant effect* in increasing the proportion of higher education qualifiers (and hence students) that study E&T at UK higher education institutions (HEIs).[7] In the absence of other approaches, it would appear that the only way to increase UK Engineering and Techinology qualifiers further is by increased procreation.

FINDING 2
Despite a huge number of initiatives in schools and colleges over the reported 14-year period to increase the number of young people in Engineering higher education, there has been no significant increase in the proportion of UK-domiciled Engineering & Technology graduates.

It is interesting to look at the numbers of A-level entrants in UK schools and colleges. (Traditionally, universities have required A-levels qualifications in Physics, Maths and Chemistry (or Biology) for entry to engineering degree courses). Fig. 7 shows the percentage of all A-level entrants in those four subjects. The problem for A-level Physics over a significant period is manifest and this has undoubtedly had an effect on E&T recruitment in HEIs.

There has been a most satisfying increase in Maths A-level numbers since the turn of the century; however, HEIs fishing in the Physics pool have been faced with a reduced catch.

Inevitably, one wonders how things are with regard to qualifiers in other JACS subject areas. This is shown in Fig. 8. Whilst there are other subjects like E&T which are remarkably static over the period (for example Medicine & Dentistry and Veterinary Science – where student numbers are regulated by Government – and Agriculture), other subjects have attracted significant

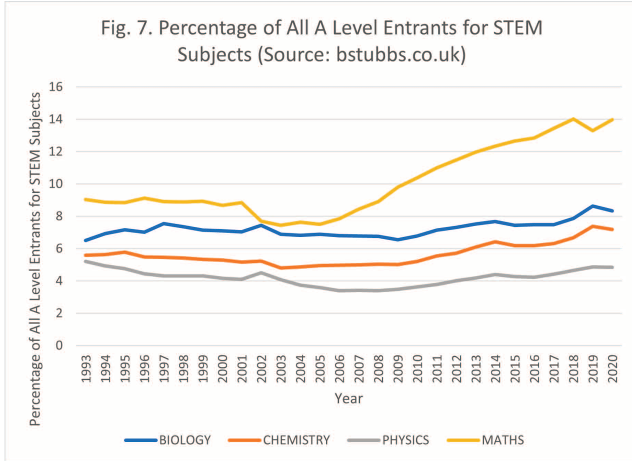

Fig. 7. Percentage of all A-level entrants for STEM subjects (Source: Institute of Physics)

increase (for example, Subjects Allied to Medicine – which have responded to extra national student-focussed bursary funding – and Biological Sciences, attractive to students looking to transfer to Medicine 'in course', or as graduate entrants). Other subjects such as Languages, Law, Combined Studies and Computer Science have been subject to striking reductions in the proportion of qualifiers (i.e. 'popularity' or 'market share') over the period reflecting university financial strategies in some cases. In other words, there is much dynamism in subject popularity or market share, and no particular reason that it should be almost constant from year to year.

It would be easy to conclude, therefore, that the skills crisis in engineering graduate numbers is unlikely to be solved by increasing outreach and intervention activities in schools and colleges, although communities may benefit from such provision as extra-curricular activity. As Einstein is often

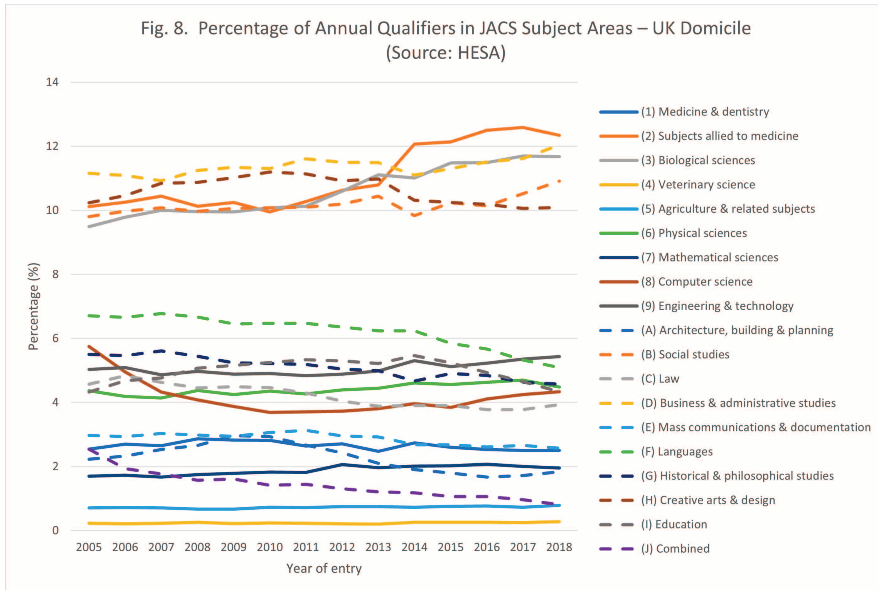

Fig.8. Percentage of annual qualifiers in JACS subject areas – UK domicile

7 Some might argue that it is precisely that huge number of outreach and intervention activities which provides the outcome shown – which would be much worse otherwise. Adherents to Occam's Razor might however dismiss such a suggestion. The introduction of the Big Bang Fair (see later) in 2009 might be regarded as a significant development, yet no significant increase in E&T qualifiers has resulted.

FINDING 3
Examination of graduate numbers across all 19 JACS subject areas over the period reveals quite dynamic behaviour with both losses and gains in market share reflecting, inter alia, regulation, popularity, available funding, and institutional marketing strategy.

quoted, "Insanity is doing the same thing over and over again and expecting different results." Alternative approaches are clearly required.

FINDING 4
The skills crisis in engineering graduate numbers is unlikely to be solved by continuing or increasing outreach and intervention strategies in schools and colleges. There is a need for different approaches to increase the appeal of E&T university programmes.

Before moving on, however, it is instructive to consider the 'principal' Engineering disciplines *within* the JACS Engineering & Technology subject area – namely in Aerospace, Chemical, Civil, Electrical & Electronic, General, Manufacturing and Mechanical Engineering. Examination of the contribution that qualifiers in each discipline make to the aggregated popularity figures for E&T yields the graph in Fig. 9.

The first and perhaps most striking feature is that over the 14-year period, the fortunes of Mechanical Engineering and Electrical & Electronic Engineering have pretty much reversed. Mechanical Engineering is on a definite upward trajectory, maybe (but this is pure speculation) aided by the IMechE's association with Formula 1 and the Bloodhound Project. Electrical & Electronic Engineering, on the other hand, has been on a plunging slide since the turn of the century. This cannot be associated with any major exodus to Computer Science, as Fig. 8 shows, and is clearly a matter for the attention of the UK Electronics Skills Foundation.[8]

Fig. 9 offers the surprising conclusion that, despite the stability of demand for Engineering degrees, there is considerable volatility within individual sub-disciplines. One such is Chemical Engineering, which whilst starting from a low base, nevertheless has more than doubled its popularity over the period. The IChemE's 'whynotchemeng' initiative is believed[9] to be partially responsible for this result; also, as Fig. 7 shows, the trend in the proportion of A-level students taking Chemistry has been rising since 2001.

On the other hand, Production & Manufacturing Engineering is bottom of the class, and has literally halved its popularity over the period, from a low base. A recent article by the CEO of Make UK (previously the Engineering Employers' Federation, EEF) in the *Daily Telegraph*[10] nevertheless sings the praises of the discipline in historically leading the industrial revolution and developing its important contribution to the economy (and to fighting the Covid-19 virus). He addresses the need "to improve our education system to equip … a new generation with the skills and abilities they need to thrive in the fourth industrial revolution" – although surprisingly this case is made without using the words 'engineer' or 'engineering' even once (see later).

Civil Engineering shows an interesting upward trajectory in early years, reaching its zenith over the period 2008/9 to 2013/14, and then falling away again. That peak period neatly straddles the period around the 2012 London Olympics with its attendant heavy activity in construction, and this may account for it. However, it should not go unnoticed that Crossrail, 'Europe's largest transport project' has been slowly progressing since its approval in 2007 and, at a projected cost of over £18bn, is somewhat bigger that the £14.6bn of the Olympics, but perhaps less in the public eye. Both those projects dwindle in comparison to HS2, estimated in early 2020 to cost £106bn which surely must excite young people as future engineers.

"Letting the market slide about of its own accord is not a responsible way of setting and achieving sustainable goals."

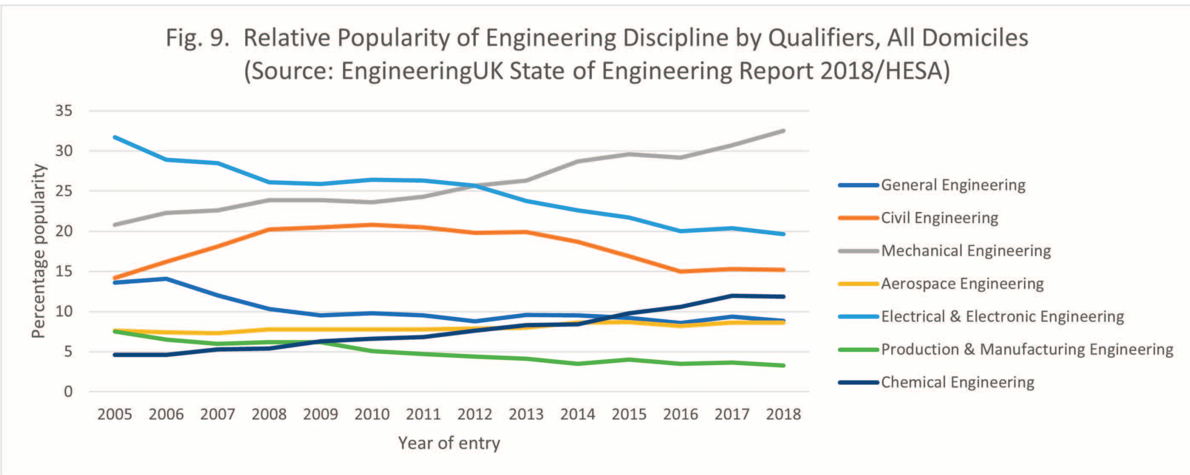

Fig. 9. (Data Source: EngineeringUK State of Engineering Report 2018 / HESA)

Aerospace, meanwhile, shows an encouragingly upward slope and General Engineering (following a decrease in early parts of the period) now seems to have achieved some sort of stability. Some commentators have suggested that this is set to increase in coming years.

Further research needs carrying out into the dynamics of popularity of the various principal Engineering & Technology subject areas; indeed, given some evidence of the development of courses in Mechatronics and Electro-Mechanical Engineering (presented as General Engineering), the JACS principal subject classification might need reconsidering. Whatever the reasons for the dynamics, it is surely important for some sort of workforce planning to guide the availability and marketing of appropriate higher education programmes in the future. Letting the market slide about of its own accord is not a responsible way of setting and achieving sustainable goals in the future.

FINDING 5
There is an urgent need to reverse the severe downward trends in the popularity of degree programmes in Electrical & Electronic Engineering, and Production & Manufacturing Engineering – both subject areas of global economic importance.

There remains in all this an enigma. The graph in Fig. 6 shows that the proportion of the total UK domiciled qualifiers that have qualified with Engineering and Technology first degrees each year from 2005/6 to 2018/19 has been almost around constant at 5% and yet the principal disciplines analysis shows considerable dynamic change over the 14-year period to date. How can this be? It would appear that young people only have so much appetite for things engineering, but the disciplines seen as fashionable or interesting – or promoted – have changed over the years. So, it seems that promotion of JACS principal engineering disciplines maybe does seem to work for those who have settled on E&T study – but in the 'zero sum' game presented, at the expense of a downturn in other disciplines. One thing is for sure – Electrical & Electronics Engineering and Production & Manufacturing Engineering (subject areas of great importance to the economy) need urgent attention to reverse their downward trends.

[8] www.ukesf.org
[9] epc.ac.uk/wp-content/uploads/2013/11/Libby-Steele-RA-Forum-2013.pdf
[10] digitaleditions.telegraph.co.uk/data/178/reader/reader.html?social#!preferred/0/package/178/pub/178/page/110/article/28718

WOMEN IN ENGINEERING

Many commentators have suggested that the lack of graduate engineers could 'simply' be corrected by attracting more women into the subject. The population of the UK is currently around 66 million, of which about 52% are female, and 48% male. In UK universities over the period 2005 – 2018, the gender percentages of qualifiers have been fairly constant, with an average of 57.8% (female) and 42.2% (male) (σ=0.3%) of total qualifiers in all subjects. Women are therefore the majority participants in higher education, which surely should bode well for participation in a discipline of such major importance to the nation, such as Engineering and Technology?

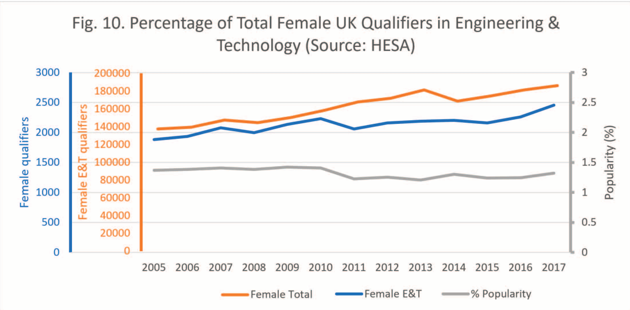

Fig. 10. Percentage of total female UK qualifiers in E&T

Fig. 10. Shows the total female UK domiciled qualifiers (in all subject areas) over time, together with the number of E&T female qualifiers. The percentage popularity of E&T for female qualifiers is also shown (the right-hand scale applies). The reduction in popularity from 2010/11 to 2011/12 is actually caused by a drop of only 69 qualifiers, but is exaggerated by the small numbers involved; suffice to say that again we see that the popularity is pretty near constant (average:1.3%, σ= 0.1%) and at a pitifully low level.

FINDING 6
Despite huge efforts to rectify the disparity in the gender balance between female and male graduates in engineering and technology for over at least a century, the facts reflect a gross under-representation of women in engineering. New thinking is required.

There are two leading organisations that seek to inspire, inform, support and celebrate Women in Engineering in the UK. The oldest, WES (The Women's Engineering Society) celebrated its 100th anniversary in 2019, whilst the second, essentially a campaign entitled Women in Science and Engineering (WISE), has been working for some 35 years. Both deserve better than the disappointing results (Fig.10 and Fig.11) for their efforts, which serve simply to stress the stark reality that the male: female ratio in E&T over the period averages 85:15 - a far cry from a wished-for gender balance of 50:50 (or indeed the ideal of 42:58 reflecting the annual overall graduating population).

In Fig. 12, we see the percentage of total female UK qualifiers in JACS subject areas dramatically increasing in Subjects Allied to Medicine (which has the largest representation of women in the cohort), the rise no doubt assisted by the availability of bursaries in the subject, and also in Biological Sciences for reasons previously noted. Subjects such as Architecture, Agriculture and E&T share a low, flat popularity, as does Veterinary Science due to recruitment restrictions.

The ratio of female to male qualifiers in the JACS Subject areas is shown in Fig. 13. (see page 12 and note the logarithmic scale used to improve clarity). Here we see the wide variations in representation of female and male qualifiers across subject areas. Given the 57.8%:42.25% gender overall split in UK domiciled higher education qualifiers mentioned above (a ratio of 1.4), it would appear that there is a gender-neutral dividing line between Medicine & Dentistry and Biological Sciences in the JACS subject areas, with subjects above Biological Sciences showing under-representation of men, and those below Medicine and Dentistry showing an under-representation of women. The sad feature of these graphs is that Engineering and Technology is the worst subject for representation of women. We cannot expect all subject areas to appeal equally to female and male students – all sorts of reasons relating to culture, history, national economic development and so on seem to have an influence around the world. Women cannot be forced to become engineers – for whatever reason, it may be that in the UK engineering is simply not an appealing proposition. All we can do is present the attractive features of a career in engineering and hope.

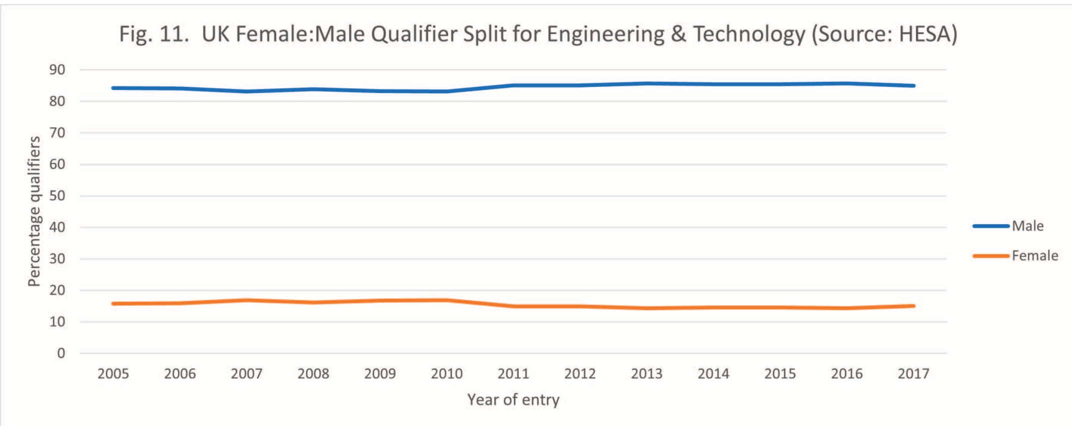

Fig. 11. UK female:male qualifier split for E&T

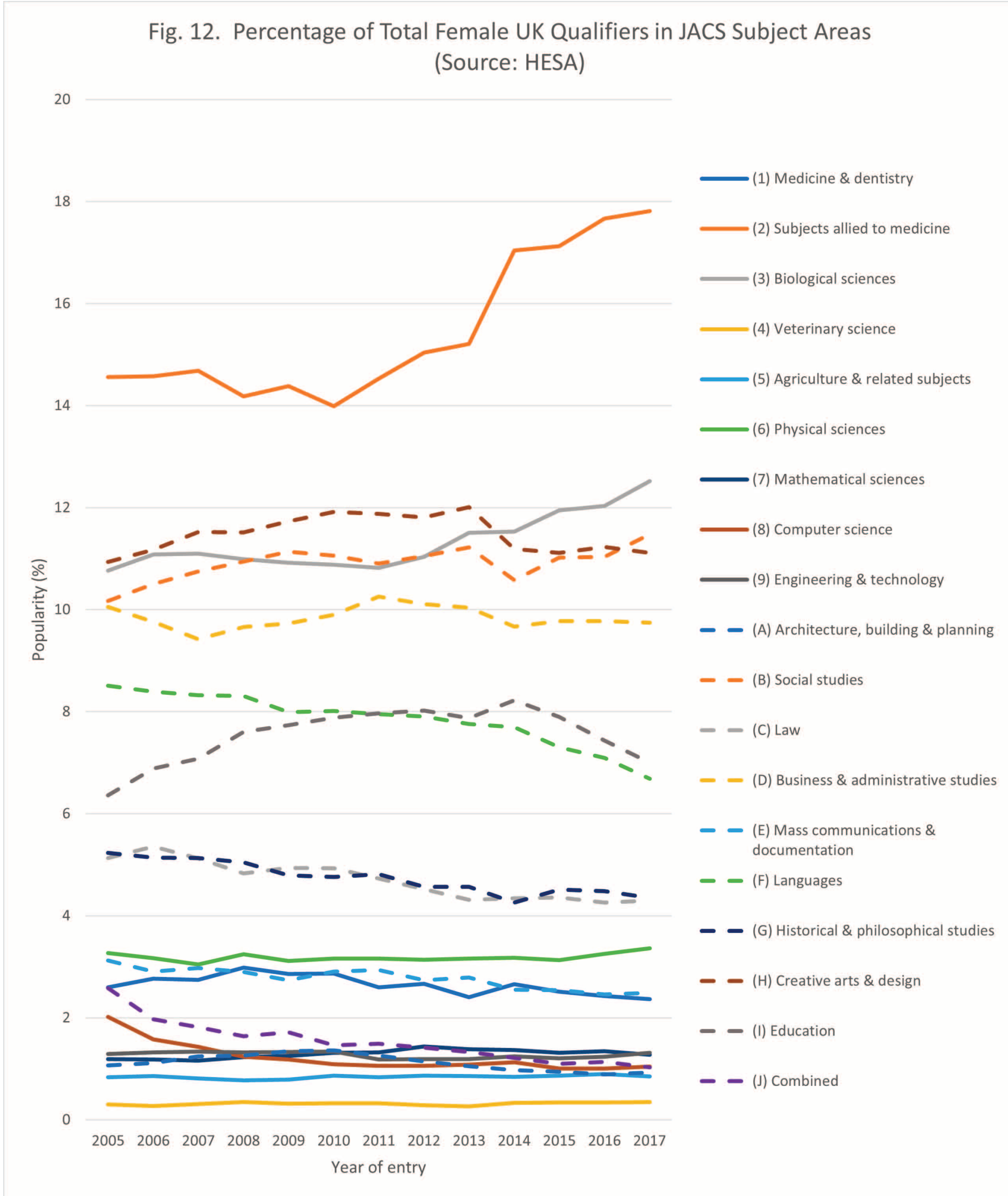

Fig. 12. Percentage of total female UK qualifiers in JACS subject areas

"Once again, we are led to the inevitable conclusion that it has proved impossible to get a significantly higher proportion of UK domiciled female students (and so qualifiers) into Engineering & Technology programmes in UK universities"

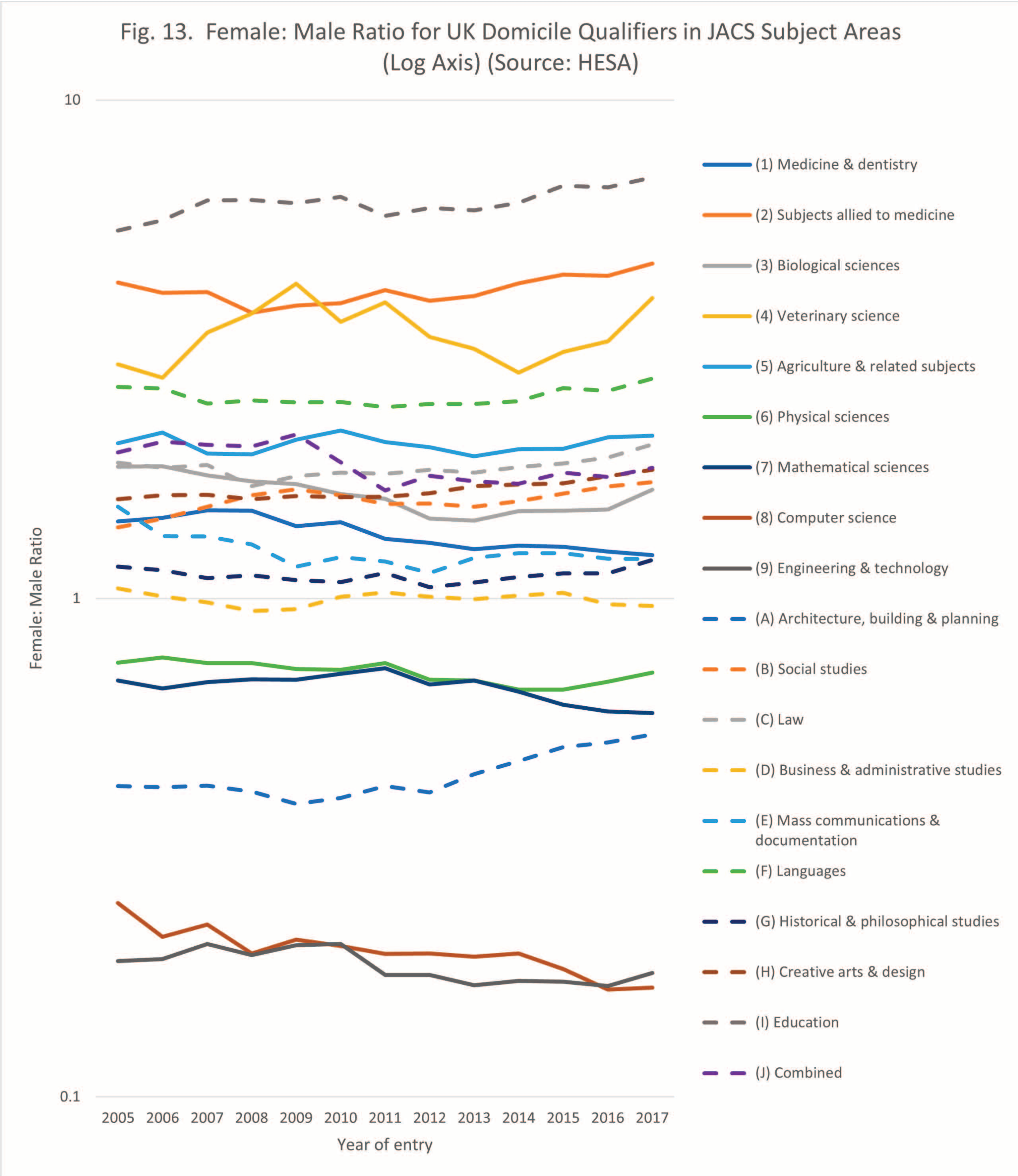

Fig. 13. Female:male Ratio for UK domicile qualifiers in JACS subject areas (logarithmic axis)

Once again, we are led to the inevitable conclusion that despite the huge efforts of WES and WISE and the general massive activities in outreach and intervention in schools, it has proved impossible to get a significantly higher proportion of UK-domiciled female students (and so qualifiers) in Engineering & Technology programmes in UK universities. Commentators have pointed out[11] that a surprising number of girls' schools do not enter pupils in A-level Physics (which reflects in the relatively low showing for Physical Science courses in Fig. 11), and this clearly does not help the problem.

(Incidentally, it is of interest to note the controversial[12] 'gender-equality paradox in STEM' that has been observed in a number of Scandinavian countries. In spite of having what are widely considered to be some of the most progressive and advanced equity and equality social policies in the world, many of these countries have seen little change in the gender-split representation in STEM fields.)

All may not be lost, however – for a very important reason. The evidence is to be found in A-Level courses. In recent times, there have been two courses relevant to our discussions here, being A-levels in Engineering and in Design & Technology (D&T). Unfortunately, A-level Engineering has never caught on to the extent hoped – indeed there were only 10 entrants in the 2018 exam season, and in 2019, sadly, zero.[13] Design & Technology, on the other hand, has shown considerable promise and has received backing from employers and industry, and notably Make UK[14] (formerly the Engineering Employers Federation – EEF).

Design & Technology arose from the flames in 1989 when it was made (initially) a compulsory subject to study, beginning in England and Wales, following the demise of subjects such as Woodwork, Metalwork and Needlework. That was a connection that seems never to have been forgotten by the public – unfortunately, as a result Design & Technology has carried an image problem, just like Engineering (see below). Design & Technology qualifications are available from several leading Examination Boards and have attracted not insignificant numbers of entrants as shown in Fig. 14. The subject, just like Engineering, is spoken of with some disdain as being a 'vocational' rather than an 'academic' subject. In other words, it provides skills and education that prepare you for a job. It that regard, it is rather like Medicine, or Dentistry,

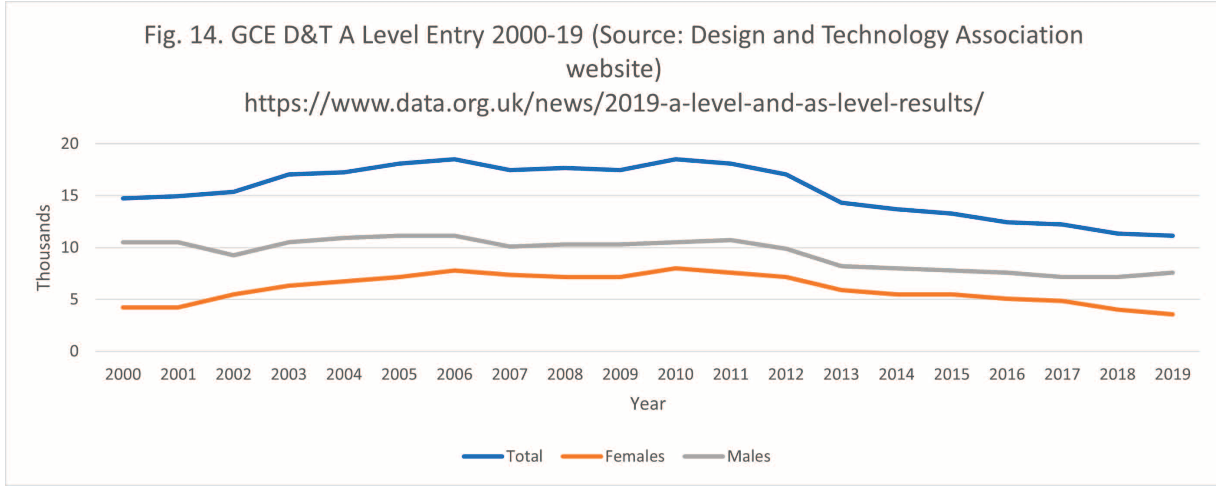

Fig. 14. D&T A-Level entry 2000-09 (Source: Design and Technology Association website[15])

Fig. 15. Keyword cloud drawn from the Design & Technology examination board syllabi

[11] www.iop.org/education/teacher/support/girls_physics/file_58196.pdf
[12] www.buzzfeednews.com/article/stephaniemlee/women-stem-gender-equality-paradox-correction

[11] assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/803906/Provisional_entries_for_GCSE__AS_and_A_level_summer_2019_exam_series.pdf
[11] www.makeuk.org/insights/reports/2019/04/26/making-design-and-technology-manufacturers-business
[11] www.data.org.uk/news/2019-a-level-and-as-level-results/

or Veterinary Science – so what, we may ask, is wrong with that?

Design and Technology as an A-level subject is very much an introduction to Engineering – an excellent primer on Materials, on Manufacture, CAD and CAM, on design approaches, and on communication, ethics and so on. The 'word cloud' shown in Fig. 15 (see page 13) is formulated from a list of keywords drawn from the examination board syllabi to give an impression of the spectrum of topics.

Despite its appeal to employers and students, all is not well with D&T. The trouble started around 2010 when the English Baccalaureate was born in the school education curricula which favoured a return to the traditional focus on non-vocational subjects. Students and their parents responded by deserting D&T courses which led to the decline shown in the Fig. 14, unfortunately exacerbated by the difficulty in finding suitable D&T teachers.

So why is this relevant to women in engineering? The answer, of course, lies in the graph of Fig. 14. Here we see that at least roughly a third of the students talking A-level D&T were female. Significantly, in 2019 47.4% of the female students gained A-B grades, against just 37.4% of the males.

FINDING 7
There is a clear disjunction between the proportion of women that engage with Design & Technology A-levels and those that show an interest in engineering degrees. This might suggest a way forward.

It is fair to say that the EBacc initiative has stalled. Targets have not been met and have been extended. There is significant concern that the return to non-vocational subjects intended by the EBacc is out of kilter with the UK's Industrial Strategy[16] (which is predicated on "Key policies including:

- Establish a technical education system that rivals the best in the world, to stand alongside our world-class higher education system
- Invest an additional £406 million in maths, digital and technical education, helping to address the shortage of science, technology, engineering and maths (STEM) skills".)

Surely the opportunity will be taken to market existing Design & Technology programmes to fulfil such policies and reinstate (indeed increase) the engagement of young people and in particular females?

It would seem therefore that if only the connection could be made between the Design & Technology discipline at school, and the engineering degrees studied at university, there would be hope for recruiting more women into engineering degree programmes (and possibly men as well).

In fact, that connection exists, and the topic is revisited later in this document.

[16] www.gov.uk/government/publications/industrial-strategy-the-foundations/industrial-strategy-the-5-foundations

SEEKING SOLUTIONS: THE CONTEXT

Several reports of an interview with Prince Philip (as Senior Fellow of the Royal Academy of Engineering) on *The Today Programme* on BBC a few years ago noted his assertion[17] that "Engineers come only second to God". His interviewer, Lord Browne of Madingley[18], (as *Today Programme* guest editor) commented slightly differently[19]: "Everything that wasn't invented by God is invented by an engineer". These welcome sentiments suggest the fundamental importance of engineering.

However, in a past report entitled *The spirit of Engineering: turning ideas into reality*, the UK House of Commons Innovation, Universities, Science and Skills Committee chaired by Lord Willis said "the extent and nature of engineers' and engineering's contribution go largely unrecognised, with people failing to make the connection between the technology they enjoy and the role of engineering".[20] Lord Browne has himself said that "people think they know what engineering is, but the evidence is they don't, and in the UK the evidence is that we are very, very bad at telling them."

There, in a nut-shell, is the problem that we face – we try to promote engineering to get more engagement (for example increasing the proportion of students studying the subject at university), but for a variety of reasons that promotion of engineering is not getting through, and having no effect, as indicated earlier.

Evidence of the problem is to be found everywhere. In a recent Institution of Engineering & Technology Report[21], IET CEO Nigel Fine reported "Two thirds of parents don't feel they know enough to help their child if asked for advice on engineering". This is a much-reported problem and there is a deal of anecdotal evidence that it extends to teachers, the media, those in Whitehall and Westminster – indeed society in general. The public simply does not understand engineering.

FINDING 8
There is substantial evidence that parents, families, those in Whitehall and Westminster, teachers, and indeed society in general – all who have great influence over the careers of young people – are ill-informed about the nature of engineering and the nature of engineering higher education.

People meet the 'engineer' that services their boiler, installs their washing machine or their broadband, or maybe services their car or 'fixes things'. However, unlike professionals that work in medicine, in law, veterinary practice or accountancy, most people will not knowingly have met a professional engineer and so know little about what they do.

"People think they know what engineering is, but the evidence is they don't"

Those of us in the profession are aware of the standing of a Chartered Engineer or an Incorporated Engineer (regarded as professional engineers) – although many of us (including even the qualification holders) probably have little if any idea what the designations actually mean, and the lay public are generally flummoxed. And whilst the designation 'Professional Engineer' is now available (its use was legally protected and jealously guarded until recently by the Society of Professional Engineers – a small body that has now dissolved), the Engineering Council has no plans to use it. That is a great pity, because the use of the descriptor 'Professional Chartered Engineer' or'Professional Incorporated Engineer' (or even just 'Professional Engineer') and the post-nominal PEng would bring the UK into line with many other countries where it has common currency and engineering is better understood.

There is a need, therefore, to promote professional engineering to the general public and bring its importance into the public's consciousness. We need more young people to take an interest in a career in engineering and we need more teachers, parents and families (key influencers in such matters) to encourage them.

[17] royalcentral.co.uk/uk/prince-philip-engineers-come-only-second-to-god-57040/
[18] Past President of the Royal Academy of Engineering and Chairman of the Queen Elizabeth Prize for Engineering
[19] www.bbc.co.uk/news/business-35201197
[20] publications.parliament.uk/pa/cm200809/cmselect/cmdius/50/50i.pdf
[21] www.engineer-a-better-world.org/media/2792/inspiring-the-next-generation.pdf

PROMOTING ENGINEERING

Perhaps the biggest player in promoting engineering in the UK is the organisation EngineeringUK.[22] Its website tells us that "EngineeringUK was formed in 2002 as The Engineering and Technology Board, a charity established to promote engineers, engineering and technology by raising public awareness". It has an 'ambition' "to inform and inspire young people and grow the number and diversity of tomorrow's engineers". ETB changed its 'trading name' to EngineeringUK in 2009.

Each year a levy is placed on CEng, IEng, EngTech and ICTech registrants' subscriptions with their Professional Engineering Institution. This is shared between EngineeringUK and its sister body, the Engineering Council (responsible for regulating the engineering profession), and is then used to "promote engineers, engineering and technology by raising public awareness". Together with income derived from other sources, it is estimated that EngineeringUK has averaged over £7 million each year (at current value) to fund these promotional activities since its inception.

EngineeringUK's activities are manifold, but two stand out as major undertakings: the annual Big Bang Fair and the Tomorrow's Engineers website. Alongside these are the EngineeringUK biennial report on *The State of Engineering* (an excellent, comprehensive and highly regarded publication); the EngineeringUK Brand Monitor; and the Skills Partnership; Robotics Challenge; Energy Quest; Tomorrow's Engineers week; and Tomorrow's Engineers Code (in which around 140 organisations pledge to work together to improve the impact of their activities). The comments here are restricted to the first two activities.

The Big Bang Fair is a relatively large enterprise that has been running annually since 2009 and billed as "The Big Bang UK Young Scientists and Engineers Fair". In its publicity it sees itself as "the United Kingdom's largest celebration of STEM for young people and is one of the largest youth events in the UK". Surprisingly, the Big Bang Fair is not just promoting engineering and technology, but also science and mathematics – all the so-called STEM areas (see later). This goes far beyond EngineeringUK's undertaking to "promote engineers, engineering and technology by raising public awareness".. EngineeringUK asserts that through their approach, whole classes or year groups attend, increasing the likelihood of reaching young people who are not already engaged with engineering.

Those who attend the Fair generally see it as 'a good day out' and many praise it for its entertainment value, although there has been evidence in the past that some visitors find it difficult to differentiate between the science, the technology and the engineering (and struggle to identify the mathematics). This casts doubt on its utility for career decisions. Is it a success? The exhibitors it attracts include many household names from industry, also the armed services, universities and colleges, and professional engineering institutions. Its analytics focus on an obvious key performance indicator – footfall. In this respect the 2019 Fair attracted some 80,000 visitors, of which 62,000 were young people, over four days. Students from 10% of nationwide secondary schools attended. Regional and local Big Bang activities swell the numbers involved to hundreds of thousands. However, as we have seen, its introduction in 2009 does not seem to have had any significant effect on the proportion of Engineering qualifiers in the UK's universities. Indeed, the Uff Report[23] (*UK Engineering 2016 – an Independent Review of Professional Engineering* commissioned by the IMechE, IET and ICE) remarked generally that "it is undeniable that [EngineeringUK's] efforts to promote increased entry to the profession have not achieved notable success". EngineeringUK has responded to this challenge, and now has a new Chair of Trustees, CEO and Strategy. Concerned onlookers now anxiously await significant changes in UCAS E&T undergraduate applications and HESA E&T qualifier numbers.

> **"Very few people share perceptions of the profession with any awareness of the creativity and innovation that forms the foundation of a career in engineering"**

Another major EngineeringUK activity is 'Tomorrow's Engineers'[24] with its new (for 2020) superbly constructed 'Neon' website[25] that holds a major resource of engineering-related material and activities suitable for school children and their teachers, and indeed parents. It is very comprehensive and offers many opportunities to find out more about engineering. However – and it is a big 'however' – click on the *What is engineering?* leaflet, and the reader is treated to this: "Engineers use maths, science – especially physics – and subjects such as D&T, computing, electronics and construction, to improve the world around us". Further on, one finds that "studying science – especially physics – and maths at school will get you off to a great start" and "You normally need to have studied maths and physics (or chemistry for chemical and biomedical engineering), or a related vocational course to Level 3, in order to apply for engineering degrees at university".

It should be noted that Tomorrow's Engineers assertion simply reflects Professor John Perkins' statement in the *Perkins Report on Engineering Skills*[26]: "Maths and science are the key gateway subjects for engineering. As a result, we need to make sure that as many young people as possible are studying rigorous curricula in maths and science (especially physics)".

Many would argue that EngineeringUK and its Tomorrow's Engineers' Neon website and the *Perkins Report* are, at a stroke, turning off many potential future engineers. As the ERA Foundation says in the publication *Changing perceptions: Opening people's eyes to engineering*[27], "With [a suggestion of] mathematics and physics forming the backbone of the academic path into engineering, it is perhaps unsurprising that many view the profession as being deeply uncreative and technical. Very few people share perceptions of the profession with any awareness of the creativity and innovation that forms the foundation of a career in engineering. Whilst young people perceive other professions to offer significant opportunity for fun, engineering is yet to harness these associations." In short many young people fear that engineering courses in higher education will involve a lot of science and maths (while being less prestigious than unsullied courses in pure science or maths) and that is anathema to them.

And this is not helped by the Engineering Council's pronouncement within AHEP 4 (considered later): "The learning outcomes continue to demand a **substantial grounding** in engineering principles, **science and mathematics**, and well-developed quantitative analytical skills – commensurate with the level of study."

In the United States, David Goldberg, co-author of the book *A Whole New Engineer*[28] and promoter of 'The Big Beacon'[29] ("a Movement to Transform Engineering Education") has been much quoted on his view that "Engineering education is not **a mind-numbing math-science death march** that casts aside thousands of capable young people who might otherwise have made effective engineers", a comment on Engineering higher education in the US that many feel is applicable in the UK. This is evidenced by the oft-found 'linear curriculum' in university engineering programmes, of maths and science leading to engineering that unduly stress the importance of maths and science at the expense of other, perhaps more appropriate topics (see later).

A profound observation of such degree programmes has been made by Prof Rick Miller, President of the (highly successful) Olin College[30] in the US, who remarks[31] that "Engineering is not [the accumulation of] a body of knowledge. Yes, it involves knowledge, but engineering is fundamentally a process, and it's the process of engineering—like what the Wright Brothers did—which is most engaging, which is most fun, and which is what students love to do as well." (This latter comment refers to the fact that the Wright Brothers achieved powered flight without reference to the mathematics or physics of aerodynamics. Others have mentioned that water wheels were introduced without reference to fluid dynamics and the steam engine was developed without the science of thermodynamics. Without doubt, the work in these areas was refined with the help of science and mathematics, but they were not instrumental in the original creative process). In short, it is creativity that is key to engineering and engineering education should not be about acquiring a body of knowledge in science and maths, much of which Engineering graduates would suggest they do not use in their day-to-day work.

Back in 2008 the US National Academy of Engineering (NAE) initiated a project entitled *Changing the Conversation* in an attempt to remedy the problems in encouraging young people into engineering. Much work has been done on 'messages' and 'tag lines' which best reflect the nature of engineering – and NAE's publication[32] of books on *Changing the Conversation* in 2008, and the associated *Messaging for Engineering* in 2013 essentially described a rebranding strategy to enhance the public understanding of engineering.[33] There appears to be no similar initiative in the UK, although the recent report commissioned by the ERA Foundation[34] (*Changing Perceptions: Opening people's eyes to engineering*) supports the recommendations. The NAE books make interesting reading. In particular the NAE's research revealed **young people were reluctant to engage in engineering because of its emphasised relationship with science and mathematics.** Thus, messages that were considered worthwhile were:

- "Engineers make a world of difference"
- "Engineers are creative problem solvers"
- "Engineers help shape the future"
- "Engineering is essential to our health, happiness and safety"

These are judged more effective than, for example, "Engineers connect science to the real world".

Engineering is a unique and all-pervasive discipline that uses science and mathematics – but is not based on those two areas any more than it is based on any of the eclectic mix of subjects that are the stuff of modern engineering – finance, economics, business, entrepreneurship and enterprise, management, quality, IT, languages, communication, marketing, sociology, sustainability, ethics, risk, philosophy, psychology, art and aesthetics, facilities, human resources and so on.

Reference was made earlier to Prince Philip's remark that "Everything that wasn't invented by God was invented by an engineer". The intimation is that everything that is not part of the natural world can be attributed to engineers. Science is

[22] engineeringuk.com
[23] www.raeng.org.uk/publications/other/uk-engineering-2016
[24] www.tomorrowsengineers.org.uk
[25] neonfutures.org.uk

[26] assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/254885/bis-13-1269-professor-john-perkins-review-of-engineering-skills.pdf
[27] www.erafoundation.org/changing-perceptions-opening-peoples-eyes-to-engineering
[28] *A Whole New Engineer*, David E Goldberg & Mark Somerville, ThreeJoy Associates, Inc, 2014
[29] bigbeacon.org
[30] www.olin.edu/about/
[31] nautil.us/issue/40/learning/ingenious-richard-k-miller
[32] www.nap.edu/catalog/12187/changing-the-conversation-messages-for-improving-public-understanding-of-engineering
[33] www.engineeringmessages.org
[34] www.erafoundation.org/changing-perceptions-opening-peoples-eyes-to-engineering

FINDING 9
The evidence is that over-stressing Science (particularly Physics) and Maths does a disservice to attempts to interest young people in Engineering higher education.

about achieving an understanding of that natural world – producing and evaluating hypothetical models of observed behaviour which are then used to predict behaviours of other possibly more complex phenomena (the Scientific Method[35]). Mathematics has an important role in this modelling activity. Thus, science allows us to understand natural phenomena – from the sub-atomic level to the dynamics of oceans and the climate; and from the smallest living creatures to the largest animals – and of course human beings and their bodies and minds. Science is about analysis.

Engineering, on the other hand, is about synthesis. As previously suggested, it is about creating things – products that in some way address and solve the problems, challenges or needs of our society. Seldom do these products arise from new scientific and mathematical developments (although there are exceptions – graphene, for example, is a material for which applications continue to be sought); on the contrary, many scientific and mathematical developments follow engineering creativity. Thus, as mentioned, the science of thermodynamics came after the creation of the early steam engines; the science of aerodynamics mostly followed the Wright brother's empirical work on practical flying machines.

The supposed continuum, such as it is, from science and mathematics to engineering is in fact in the reverse direction – it is engineering creativity that often gives rise to developments in science and mathematics. Progress in semiconductor physics (for microchips) and the development of the mathematical fast Fourier transform used in signal processing are particular examples, often involving work at the boundaries of both science and engineering. Too much concentration on analysis is usually at the expense of that most important component of the essence of engineering: *creativity*.

[35] www.britannica.com/science/scientific-method

THE PROCESS OF ENGINEERING: CREATIVITY

"Creativity is 'having ideas of value', resulting from 'applied imagination'"

Sir Ken Robinson[36] has defined creativity as 'having ideas of value', resulting from 'applied imagination'. Others take a similar view. Google lists definitions such as 'creativity is a phenomenon whereby something new and somehow valuable is formed' or it is 'the use of imagination or original ideas to create something; inventiveness' or, rather more grandly, 'creativity is the process of bringing something new into being. Creativity requires passion and commitment. It brings to our awareness what was previously hidden and points to new life. The experience is one of heightened consciousness: ecstasy.'

We get the idea. But few people have the luxury of having a free rein in being creative – most engineers are being creative in their search for a solution to a problem suggested by a customer or client. The solution is a 'product' (which may be tangible or intangible, or a service). The first step to creativity is in extracting and analysing the customer needs. This necessitates answering questions such as 'How does the problem arise? Where, and how large, is the market? To what price and margin are we working? What is the time frame to completion? How big and heavy will it be? In what environment will it operate? What are the competitor products? Is this an improvement on an existing product?' Only when the customer needs have been identified (also known as the 'requirements specification') can thoughts turn to those requirements on the product that result, in terms of size, shape, weight, complexity, appearance, technology and so on. All these things will translate into the constraints under which the engineer's creative talents must operate and are thus part of the creative process.

At this point, creativity starts in earnest. Much has been written on how to do this – and clearly whilst ideas emerge mainly from thought, this can be enhanced by brainstorming with others, by doodling, by mind maps, by practicing de Bono's 'lateral thinking', with incubation (taking a break, and letting your 'background processor' get on with things), always nodding towards Occam's Razor[37] (or in modern parlance, 'Keep It Simple, Stupid" – KISS[38]), through research, serendipity and so on. As a result of such activities, an idea of how to meet the customer's needs gives rise to an invention. Checking out that idea – perhaps with a prototype – is termed 'proof of concept'. Now, bringing the idea to market, to reality, requires *innovation*.

[36] *Out of Our Minds: Learning to be Creative*, Sir Ken Robinson, 2011
[37] www.britannica.com/topic/Occams-razor
[38] en.wikipedia.org/wiki/KISS_principle

THE PROCESS OF ENGINEERING: INNOVATION

> **"Innovation is about bringing ideas into reality, bringing them to market"**

Innovation is a process that calls on a wide variety of subjects including, but beyond, science and mathematics. This includes, *inter alia*, that eclectic mix mentioned above: finance, economics, business, entrepreneurship and enterprise, management, quality, IT, languages, communication, marketing, sociology, sustainability, ethics, risk, philosophy, psychology, art and aesthetics, facilities, and human resources. All these subjects (and more) contribute to innovation.

Frequently confused with invention, innovation, as mentioned is about bringing ideas into reality, bringing them to market. These may be improvements on existing ideas or products, or they may be something new arising from the creative process. In practice, innovation encompasses a wide range of 'liberal' subjects and is a process that ensures the product is *feasible*, *viable* and *desirable*, and can thus be delivered to the customer and perhaps then to the market.

Feasibility requires that the product satisfies scientific laws (i.e. no perpetual motion machines) and that mathematical and physical constraints are satisfied. It also requires that existing or new proven technologies are available for the product's realisation. Viability, meanwhile, implies that the means exist that will lead to fulfilment of the project – for example the buildings, equipment, materials, supply chain, human resources, financial facilities, legal requirements, health and safety arrangements, quality systems and so on. Finally, desirability has implications that the product is aesthetically and ethically acceptable; and, for example, that it satisfies environmental, ecological, sustainability and social constraints.

THE PROCESS OF ENGINEERING: DESIGN

> **"Design is what links Creativity with Innovation"**

Of central importance is design. Design has been defined by Sir George Cox[39] (past Chairman of the Design Council) in his 2006 report as follows: "Design is what links creativity and innovation. It shapes ideas to become practical and attractive propositions for users or customers. Design may be described as creativity deployed to a specific end." Design goes way beyond the 'look' of something (its 'form'). In the context of engineering, design covers design for form, for function, for manufacture, for operation, for reliability, for maintenance, and for disposal. As someone said, design is not 'applied art', but is a rigorous discipline with its own defined approaches to achieving specific outcomes.

So, design is the process that links creativity with innovation. Design takes a new idea – an invention – and develops and transforms it into a feasible product. In rare cases (for example the design of electronic filters), design can be achieved through a number of mathematical steps – a so-called 'cookbook' method. In most approaches to design, however, there are far more variables than constraints and many cannot be quantified (for example, aesthetic appeal) and so design can give rise to a whole range of possible solutions (any visit to a camera shop illustrates this). In such cases, marketing and consumer choice is the final arbiter of a design's success.

Mention was made above about the multiplicity of design objectives in engineering – from design for form and function through to design for disposal in the product's life cycle. There are many approaches to this. Top-down design (often referred to as stepwise refinement) for example breaks a design requirement into a number of sub-requirements. Each of these sub-requirements is then further broken down until levels are reached where the solution is obvious or straightforward. The product is then the accumulation of all the items at the end levels reached.

Other approaches include *iterative synthesis* where computer models are produced for the salient features of the product components and numerical (computer-based) optimisation techniques are used to find an acceptable solution. At the other end of the scale lies trial and error, roughly described as *guess, evaluate, explore (modifications)* and formally described as *iterative design*.

So here we have the blessed trinity – creativity, design and innovation – the distilled quintessence of *the process of engineering*. It is that triumvirate that is central to the CDIO engineering education initiative[40] (*conceive, design, implement, operate*) that has been adopted by pioneering HEIs across the world.

With everything in place, the product can then be brought into being.

It is suggested that to truly engage people with engineering, we need to avoid an over-emphasis of the role of science and mathematics but stress the creativity-design-innovation process of engineering and, in doing so, increase the appeal of engineering as a career to a wider range of young people (see later). Equipping students with the skills acquired in embracing *the process of engineering* has the particular advantage that, being insensitive to technological advances, it 'future proofs' their qualification.

FINDING 10
Engineering higher education should not be seen as the accumulation of knowledge (typified by courses in science and maths leading to engineering topics), but as engagement with *the process of engineering*. This process involves creativity, design and innovation as the main activities in taking a customer requirement through to practical realisation.

A number of higher education institutions around the world are recognising that a wide variety of subject qualifications and interests (such as listed in the eclectic mix above) are appropriate to study a degree in Engineering and swell the ranks of professional engineers supporting sustainable economies with young people who have not been put off because of a stress on science and maths.

[39] *The Cox Review of Creativity in Business*, Sir George Cox, 2006
[40] www.cdio.org

FIT FOR PURPOSE?

We have seen that despite considerable work and expenditure of huge financial resources, young people in the UK have resisted and continue to resist efforts to interest more of them in degree programmes in Engineering. As mentioned, this is not helped by the insistence on portraying level 3 Science and Maths secondary school qualifications as a preferable requirement for university entry into engineering and the messages that this sends out about the nature of Engineering higher education courses. Furthermore, parents, teachers, those in Whitehall and Westminster and the general public do not understand the nature of engineering, and we engineers have not been good at enlightening them. And nor has the media (see later).

To understand this better, it is informative to consider something about how we arrived at the present position with regard to Engineering higher education courses and where we might go in future.

"Despite considerable work and expenditure of huge financial resources, young people have resisted and continue to resist efforts to interest them in careers in engineering".

1978 saw the publication by the Institution of Electrical Engineers[41] of the seminal Merriman Report (*Qualifying as a Chartered Electrical Engineer*)[42 43] which proposed that "The Institution should set up an accreditation mechanism to identify degree courses which satisfy its revised educational requirements and to monitor the development of enhanced degree courses". This was part of a strategy to raise the standard and status of Chartered Engineers working in industry, one aspect being to raise the required level of degree qualification from a Pass degree (where it had been since 1958) to second-class honours.

Before exploring those 'revised educational requirements' we should note that Merriman's comments about an accreditation mechanism for the IEE were echoed and reinforced across the entire engineering sector by the influential 1980 Finniston Report (*Engineering our Future*)[44] that gave rise to the 'enhanced and extended' integrated undergraduate Master's degree – the MEng that has remained in place as the 'exemplifying qualification' towards Chartered Engineer status. There followed development of substantial degree accreditation activity that continues today across all the major professional engineering institutions, where armies of voluntary accreditors and PEI support staff accredit literally thousands of engineering degree programmes presented by UK's higher education institutions.

Finniston called for accreditation to be carried out by a "new statutory engineering authority". The rest, as they say, is history – a history which almost 40 years later has seen accreditation in fact become the responsibility of the Engineering Council that sets the standards through the *Accreditation of Higher Education Programmes*[45] (AHEP, which forms part of UK-SPEC, the UK Standard for Professional Engineering Competence[46]). In practice the Engineering Council licenses a number of PEIs to undertake individual accreditation events on its behalf, or through the auspices of the Engineering Accreditation Board[47] (EAB) to participate in multiple-PEI accreditation activities where this is appropriate. The Institution of Civil Engineers, the Institution of Structural Engineers, the Chartered Institution of Highways and Transportation, and the Institute of Highway Engineers carry out their accreditation activities through the JBM, the Joint Board of Moderators[48]. By its very nature, AHEP has to guide some 40 PEIs[49] and must therefore be fairly generic; it is for those individual PEIs to interpret AHEP satisfactorily for their engineering disciplines; and it is for the quality assurance aspect of the Engineering Council's activities (as regulators of the engineering profession) to ensure that this interpretation is appropriate and in place.

What, though, is the stated purpose of accreditation? The IET comes straight to the point[50]: "Accreditation is awarded to higher education programmes that meet the educational requirements of the UK Standard for Professional Engineering Competence (UK-SPEC) as outlined in the Accreditation of Higher Education Programmes (AHEP)". Meanwhile, IChemE states[51] "IChemE degree accreditation provides benchmarking of academic programmes against high, internationally recognised standards." These are typical statements from PEIs, which all signpost, implicitly or explicitly, the Engineering Council and AHEP. An accredited qualification provides the educational base for the professional engineering qualifications of Incorporated Engineer (BEng) and Chartered Engineer (MEng) respectively.

[41] The IEE became the IET in 2006 with the inclusion of the Institution of Incorporated Engineers (IIE)
[42] *Qualifying as a Chartered Electrical Engineer – The Merriman Report*, The Institution of Electrical Engineers, May 1978.
[43] *Engineering Degrees and the Chartered Electrical Engineer* (pamphlet accompanying the Merriman Report), Institution of Electrical Engineers, 1978.
[44] *Engineering Our Future*, Report of the Committee of Inquiry into the engineering Profession, Department of Industry, 1980
[45] *Accreditation of Higher Education Programmes*, Engineering Council, www.engc.org.uk/ahep.aspx
[46] *UK Standard for Professional Engineering Competence*, UK-SPEC, www.engc.org.uk/ukspec
[47] www.engab.org.uk
[48] www.jbm.org.uk
[49] www.engc.org.uk/about-us/our-partners/professional-engineering-institutions/
[50] www.theiet.org/academics/accreditation/
[51] www.icheme.org/membership/accreditation.aspx

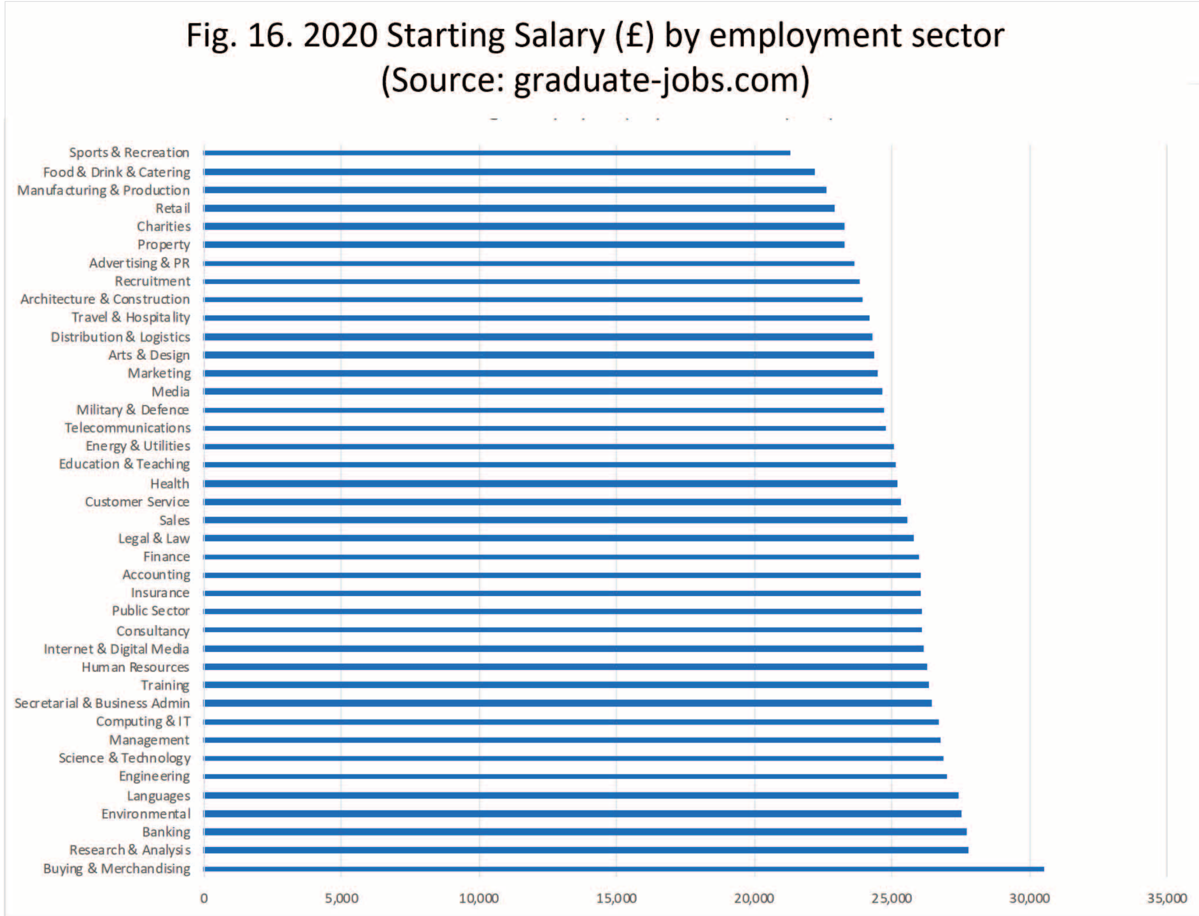

Fig. 16. 2020 Starting Salary (£) by employment sector (Source: graduate-jobs.com)

"By its very nature, AHEP has to guide some 35 PEIs, and must therefore be fairly generic; it is for those individual PEIs to satisfactorily interpret AHEP for their engineering discipline".

A particular benefit of the accreditation of academic engineering qualifications is that it enables comparison with similar qualifications in other countries, thus determining 'substantial equivalence' where it exists. Qualifications so identified are grouped in a number of 'accords', these being the Dublin Accord for Engineering Technicians, the Sydney Accord for Engineering Technologists/Incorporated Engineers and the Washington Accord for Chartered Engineers. These accords are useful in facilitating mobility of engineers between the counties represented within them.

The documentation presented by the Engineering Council on its website states that the standards that must be met for an educational programme to be accredited are set out in its handbook[52] and are derived from UK-SPEC. UK-SPEC describes the competence and commitment requirements that have to be met for professional registration; accredited programmes provide some or all of the educational element for eventual registration as IEng or CEng. The latest standard (AHEP4 - published in 2020 for implementation in 2021[53]) is to be found there.

AHEP 4 states that "all students deserve an engineering education that is world-class and that develops industry-relevant skills. Accreditation of degree programmes helps to ensure that UK engineering education meets these needs as well as drawing students towards a career in the engineering profession."

Here we find articulated the two main purposes of accreditation. First, to drive up the quality of engineering degree course provision in HEIs. It is no accident in this regard that since 2006 (and one of only a few of the subjects offered across higher education), the Quality Assurance Agency for

[52] www.engc.org.uk/media/3464/ahep-fourth-edition.pdf
[53] www.engc.org.uk/media/3464/ahep-fourth-edition.pdf

Higher Education (QAA) Subject Benchmark Statement[54] for Engineering has been word-for-word the same as AHEP.

The second purpose of accreditation is, quite unashamedly, the development of industry-relevant skills in students.

Returning to the educational requirements stated in both the Merriman Report and its accompanying pamphlet, in general terms it was proposed that there must be development of 'professionalism' – "an almost indefinable but readily recognisable set of personal attributes, which characterise an engineer's ability to master the changing environment of (their) work". Those important personal attributes include capability, initiative and imagination, creativity, practicality of judgment, self-motivation, and ability to communicate and to work in teams, all "engineering attitudes relevant to the highly competitive world of industry and commerce." (In recent times, these have been referred to as 'key skills'.)

Specifically, the report mentions that there should be a wider first-degree curriculum, a greater emphasis on applied projects and, inter alia, topics such as design, industrial management and organisation, products and production, buying and contracting, finance, accounting and costing systems, project management, marketing and a modern foreign language – "course elements that should enable the potential chartered engineer to fill roles in industry more effectively", and so be "better suited… to meeting the needs of industry".

Merriman expects that the major technical components of the course will be supported by suitable practical and project work or both, and contain elements of 'the design approach', whilst integrating some understanding of the theoretical and scientific principles underlying engineering with experience in applying such principles to real-life engineering problems.

The stress on real-life problems is further echoed in the Finniston Report, which talks of "the precepts of teaching for economic purpose" in the establishment of the (then) new BEng and MEng degrees. It is interesting to note the statement that there should be "no presumption that the academic stage of formation instils the theory leaving the practice to be 'picked up' in employment." Finniston articulates the approach through the introduction of topics in undergraduate engineering courses on 'Engineering Applications' EA1 (introduction to the fabrication and use of materials) and EA2 (application of engineering principles to the solution of practical problems based on engineering systems and processes), but making it clear that these are not discrete modules, but are integrated into the courses, alongside "Business techniques relevant to … engineering solutions through case studies and worked projects', thus "instilling a high level of understanding in several engineering disciplines."

All that was 40 years ago. The question is, where have all those high ideals in the development and accreditation of improved degree programmes brought us?

The IET provides one set of answers, in its *Skills and Demand in Industry 2016 Survey*[55] of 403 employers across the range of size and activity[56]. Among several other indicators, the report states:

- **68%** of employers are concerned that the education system will struggle to keep up with the skills required for technological change.
- **62%** are concerned about graduate skills. (A figure that has been growing steadily for many years – this confirmed in the 2017 report[57]).
- **59%** of those that feel the content of Engineering and Technology degrees do not suit the needs of their organisation say it is because they do not develop practical skills (a problem re-emphasised in the 2019 report (based on interviews with 701 employers) as a lack of 'workplace skills').[58]
- **31%** of those that are or have recently experienced problems recruiting Engineering and Technology graduates, feel that attracting candidates with sufficient work experience is a key problem in graduate recruitment.

Graduates were found wanting to varying degrees in topics including practical experience, leadership and management skills, business acumen, technical expertise, communication skills, ability to work on their own initiative, Ability to work across interdisciplinary teams, literacy skills, teamwork, and numeric skills. The report is far from positive and suggests that many of the tenets of the Merriman and Finniston reports are not being met.

(The importance of business-related skills was stressed by David Falzani, President of the Sainsbury Management Fellows[59], who in his 2018 Annual Dinner speech stated "Considerable research shows that introducing business education to young engineers makes them better engineers, makes them more employable and effective in the workplace, and is better for the profession and for the UK economy.")

FINDING 11

Engineering higher education programmes should represent the convergence of a number elements: The fundamental and enduring principles and standards extolled by Merriman and Finniston; the statement of these standards expressed by AHEP; the interpretation of AHEP by professional engineering institutions for their subject disciplines in their accreditation activities; and the compliance of academic departments in higher education institutions with those accreditation requirements.

There is clear evidence that there is often a disjunction between employers needs and higher education's provision in this regard.

[54] www.qaa.ac.uk/en/Publications/Documents/SBS-engineering-15.pdf

[55] www.theiet.org/factfiles/education/skills2016-page.cfm

[56] These surveys have been published yearly after 2006. The 2016 survey was particularly detailed in its observations and these were confirmed in the 2017 survey (with *c.*800 employer interviews). There was no 2018 report (when the IET moved to a biennial cycle). The 2019 survey (*c.*700 employer interviews) speaks particularly about the problems of 'workplace skills'.

[57] www.theiet.org/factfiles/education/skills2017-page.cfm

[58] www.theiet.org/impact-society/factfiles/education-factfiles/iet-skills-survey/iet-skills-survey-2019/

[59] www.smf.org.uk

In other words, all is not well. Further concerns are to be found in a variety of sources, some evidence-based, some anecdotal and no doubt some mythical. There does seem to be a continuing problem that employers believe the Engineering higher education programmes are not teaching, and students are not learning, fundamental skills extolled by Merriman and Finniston in their ground-breaking reports.

In a study commissioned by the Royal Academy of Engineering[60], Dr Ruth Graham explored the role that teaching plays in academic career advancement. When university academic staff members were asked about how important different factors are in promotion to full professor, more than 90% answered that research is "very important". Only 12% answered the same about teaching and education. However, 60% of the respondents would like teaching to be very important. There is a worry therefore about whether university Engineering departments are taking accreditation requirements seriously if research is their priority.

In a presentation to the IET/EPC Conference on New Approaches to Engineering Higher Education[61] held at the IET in May 2017, Prof Janusz Kozinski, founding Dean of the Lassonde School of Engineering in Toronto, Canada, and then founding President of NMiTE in Hereford, commented on the fact that only 5% of UK engineering graduates carry on to research degrees, yet many degree programmes assume that the figure is 100% in their curricular content. The implication is that many syllabi do not reflect the needs of industry.

There is also a view that the best graduates in such programmes stay on to study for a PhD, and then join the academic staff, thus perpetuating course material that is divorced from engineering in practice (of which many staff have little or no experience).

In a 2015 report[62] by Oxford University's Centre for Skills, Knowledge and Organisational Performance (SKOPE), an analysis of graduate employment in engineering led to the remark that "the fraction of those graduating from particular engineering disciplines who go into the corresponding industry sector (in particular within manufacturing) is not only not 100 per cent, but generally less than 50 per cent and, in some cases, less than 10 per cent", and so "it is not easy to support serious arguments that there might be any substantial shortages of engineering graduates, in particular in aerospace, electronics, and electrical and chemical, process, and energy engineering. "An alternative explanation is that engineering graduates, having experienced the reality of an HEI engineering education, are put off the prospect of employment in the area, and seek other things. On the other hand, one might reach the conclusion that the deficiencies of engineering degree programmes and/or the quality of the graduates is preventing employers from hiring them.

One thing is certainly for sure – it cannot be starting salaries[63] that are putting graduates off engineering employment. As Fig. 16 shows, Engineering (and cognate subjects) starting salaries compare very favourably with those in other employment sectors.

One is led inexorably to three obvious questions. In its attempt to develop industry-relevant skills in students, is AHEP fit for that purpose? Do the PEIs properly and thoroughly interpret AHEP for their discipline in accreditation activities? Are our HEIs taking engineering education seriously? Employers' remarks clearly signal a disjunction between their needs and higher education's provision.

It should be said that there is currently a wide spectrum of university engagements with industry. There are examples of significant and effective alignment of higher education provision to the needs of industry/employers. The Warwick Manufacturing Group[64] is often held-up as an international role model for successful collaboration between universities and public and private sectors. Coventry University is also noted for its Institute of Advanced Manufacturing and Engineering programme[65] – developed and delivered in conjunction with the Unipart Manufacturing Group. Of particular note is the Royal Academy of Engineering Visiting Professors Scheme[66] that forges partnerships between industry-based engineers and a visited university in a three-year, twelve days per year, funded scheme. However, as the IET surveys indicate, there is considerable room for improvement.

Much has changed in recent years in our society. Our undergraduate students enter higher education as experts in the use of technology. The internet and social media are second nature to them and they are immersed in an 'on demand', 'box-set' culture of information gathering and entertainment. A growing number of pioneers around the world are taking advantage of this in the development of new 'active learning' approaches to Engineering higher education that embraces the technology of learning. In this way, the conventional lecture room approach of the lecturer's slides being transmitted to the student's notes is being replaced by the 'flipped classroom' model where students acquire appropriate (to their needs and the needs of the project) knowledge online, by reading books or by discussion with other students whilst the classroom becomes the space with physical resources for practical approaches to learning by providing a work-based 'studio' environment where industrially relevant skills can be inculcated.

It is suggested that the active learning vehicle for inculcating the engineering process and providing and developing the practical experience, leadership and management skills, business acumen, technical expertise, communication skills, ability to work on one's own initiative, ability to work across interdisciplinary teams, literacy skills, and teamwork is **problem-based learning (PBL)**. Here students work in small groups (5 to 6 students) on real-world projects over extended periods. This approach is being developed by many universities

[60] *Does teaching advance your career?*, Royal Academy of Engineering, www.rhgraham.org/resources/Template-for-Evaluating-Teaching-Achievement.pdf

[61] epc.ac.uk/wp-content/uploads/2017/06/New-Approaches-Conference-Proceedings-book-final.pdf

[62] *The Scale of 'Leakage' of Engineering Graduates from Starting Work in Engineering and its Implications for Public Policy and UK Manufacturing Sectors*, SKOPE Research Paper No. 122, January 2015, Dr Matthew Dixon

[63] www.Graduate-jobs.com

[64] warwick.ac.uk/fac/sci/wmg/

[65] www.coventry.ac.uk/ame/

[66] www.raeng.org.uk/grants-prizes/grants/schemes-for-people-in-industry/visiting-professors-in-innovation

globally. (See the 2018 MIT report on *The Global State of the Art in Engineering Education*, again prepared by Dr Ruth Graham.[67]) As would happen in industry, not all group members would need expertise across all subject areas such as those mentioned above. Indeed, the eclectic list of topics opens the opportunity to recruit students with a wider range of backgrounds and interests and so reduce that aspect of the skills crisis. This accords with the 2019 report from the National Centre for Universities and Business (NCUB) *Talent 2050: Engineering Skills and Education for the Future*[68] that sees Engineering higher education not as part of the Perkins Report "leaky pipeline" of A-level Maths and Science qualified students, but as engaging with the "reservoir of talent" of **"ready-to-learn students, chosen for their potential to gain the right skills rather than their previous attainment"**.

In other words, students learn how to attain the appropriate level of knowledge and understanding required to solve problems through simple approaches to *content mastery* (effectively, knowing how to look for information using the resources available) and *lean learning* (developing skills in extracting just enough information to progress the problem in hand). Such approaches are being developed through 'toolkit sprints' by NMITE[69] and the 'learning tree' by TEDI-London.[70] So, this is a new world, a world where students are not required to have A-levels in Science and Maths for admission to Engineering degree programmes but may enter with backgrounds and interests that span that eclectic mix of subjects that are the stuff of modern engineering previously mentioned. Moreover, as intimated earlier, this is a world where an A-level qualification in Design & Technology would provide a wonderful introduction to further study and precursor to an Engineering degree – not only in subject matter (and note the number of topics in the forgoing that are mentioned in the 'word cloud' of Fig. 15.) but also in its proven appeal to female students and thus providing a solution to the problems of women in engineering discussed previously. **If the government is serious about the importance of engineering in supporting and developing a sustainable economy, in pursuing its 'levelling up' agenda, and in promoting inclusion, then it must urgently rethink its approach to education and not simply pander to misplaced prejudice by people who do not understand engineering and its value to society.**

It is also the new world of higher apprenticeships where students study a degree in engineering part-time in an HEI, and work in industry. What better way to develop industry-relevant skills than to work in industry on actual projects? Such developments are worth noting both with respect to co-developing programmes with employers/employer groups and also innovation in curriculum and pedagogy which better meets the needs of employers. At the time of writing, 30 universities[71] (all but six post-92 institutions) are running

"So, this is a new world, a world where students are not required to have A/Levels in Science and Maths for admission to engineering degree programmes but may enter with backgrounds and interests that span that eclectic mix of subjects that are the stuff of modern engineering"

engineering degree apprenticeship schemes, and clearly there is room for further engagement.

There are of course challenges in implementing these new approaches. In particular, what does success look like in the engineering education of our undergraduates? If we are inculcating more business- and industry-relevant skills, what has to give? How do we square the successful inculcation of skills in students' engagement with the 'process of engineering' and QAA credits?[72]

There are without doubt groups currently considering such matters, particularly in the area of degree apprenticeships – seeing how AHEP can be adjusted to accommodate such special cases. That may be the wrong approach, however. Given that accreditation seems not to have provided the correct results over the past 40 years (for example from the evidence in the IET reports), perhaps it is time for a root and branch review of accreditation for this new world where those who persist and insist in providing a classroom lecture-based linear curriculum (built on an assumption that engineering is the practical application of maths and science) should become the special cases?

Perhaps AHEP needs a completely fresh look (rather than incremental updates) and needs to be a little more proactive (but not prescriptive) in recognising the changes that are occurring globally in Engineering higher education. By way of an example, consider this paragraph which appears in AHEP 4 document (published in 2020): "Higher education providers are encouraged to develop innovative degree programmes in response to industry needs and the Engineering Council does not favour any particular approach to teaching, learning or assessment. The key consideration is that all graduates from an accredited degree programme must meet all of the prescribed learning outcomes". Could it not signpost possible effective approaches for investigation? Is it really the case that all graduates must meet all learning outcomes?

This seems inflexible and certainly does not accord with

[67] neet.mit.edu/wp-content/uploads/2018/03/MIT_NEET_GlobalStateEngineeringEducation2018.pdf
[68] www.ncub.co.uk/images/reports/NCUB_Talent2050_Skills_and_Education_Report_Final.pdf
[69] nmite.ac.uk
[70] tedi-london.ac.uk/
[71] www.thescholarshiphub.org.uk/universities-offering-degree-apprenticeships/
[72] www.qaa.ac.uk/docs/qaa/quality-code/academic-credit-higher-education-in-england-an-introduction.pdf
[73] issuu.com/nationalcentreforuniversitiesandbusiness/docs/4614_ncub_talent2050_skills_and_edu

NCUB's proposal for three 'skills pillars'[73]: people skills, creative thinking and enterprise, alongside core technical knowledge?

Furthermore, on assessment, AHEP asserts: "Assessment should be designed to minimise opportunities for students to commit academic misconduct, including plagiarism, self-plagiarism and contract cheating. Wherever possible, a suitable variety of assessment methods should be used, to minimise the availability of opportunities for students to incorporate plagiarised work by another author, or previous work by the student, either within the level of study or across levels. Policies and procedures relevant to academic integrity should be clear, accessible and actively promoted rather than simply made available". Important though the problem of plagiarism has become[74], focusing on it narrowly is unduly negative. It could mention the benefits of students having a portfolio illustrating their creative work in problem-based learning; a profile of their 'skills' achieved through that creative work; and so on.

There is room for a continuation of Engineering degree programmes that are effectively Engineering Science (see Appendix 1) – suitable for students that want to follow a more theoretical approach to Engineering. Without a doubt, the graduates would hold important skills that contribute to sustainable development. However, there is a clear argument that for the majority of Engineering graduates, their qualification should reflect an engagement with *the process of engineering* – with creativity, design and innovation.

As observers have commented, "An outdated 20th-century curriculum, offered through a 19th-century delivery system, will neither attract creative, broad-minded students with a passion to change the world, nor will it equip them with the skills they need to effect that change. Fundamentally new approaches are required."

In summary, we need a radical reassessment of modern Engineering higher education; and we need a radical reassessment of the measures that need to be taken to assure its delivery.

FINDING 12
The world is changing, and the world of Engineering higher education with it. In the UK, to attract more young people into the profession we need a radical reassessment of our Engineering higher education programmes and of the measures that need to be taken to assure their delivery.

"Mention the benefits of students having a portfolio illustrating their creative work in problem-based learning; a profile of their 'skills' achieved through that creative work, and so on"

[75] www.plagiarism.org/article/plagiarism-facts-and-stats

PERCEPTIONS OF ENGINEERING IN THE MEDIA

There is no shortage of papers on the public perceptions of engineering[75], nor anecdotal evidence of the problems that exist – tales of notices in supermarket toilets announcing that a hand drier is out of order, but that 'an engineer has been called'; newspaper photographs of 'engineers' clearing the leaves from railway lines; a Royal Navy television advert in recent times that suggested, "if you can fix a skateboard, you can fix a bike, and if you can fix a bike, you can fix a car, and if you can fix a car, you can learn to fix a helicopter, a seaboat, a naval gun, a radar system, a destroyer. And when you can fix all that, you will be a Royal Navy Engineer". In other words, according to popular belief, engineers 'fix things'. (A more recent version[76] of the Royal Naval advert makes interesting comments on starting salaries of graduate recruits compared with those with no qualification.)

This is one perception of engineers and engineering. National Grid UK produced a report in the recent past (*Engineering Our Future: Inspiring and attracting tomorrow's engineers* – sadly, no longer available – a recent US National Grid version is available[77]) which suggested that:

- *Engineering is seen as a job rather than a profession. The work has an image of being menial, dirty and about fixing things. Because of this association with blue collar work, it is seen as a dying industry.*
- *It is almost an invisible industry and for many young people is simply not on their radar as a career option. For example, 6 out of 10 young people cannot name a recent engineering achievement.*
- *This leads to low appreciation of what engineers do for society. Both parents and young people placed engineering below medicine, teaching and policing in its contribution to modern life.*
- *There is snobbery among some parents who think their children could do better than choose engineering.*
- *And unhelpful gender stereotypes mean that for every ten boys who would consider engineering as a career, there is only one girl.*

Much of the public perception is, of course, influenced by the media. In their innocence, media outlets often totally ignore engineering. Indeed, what attention they give to engineering often relates to engineering workers rather than technicians or professional engineers; and references to engineering achievements are often attributed to science or scientists. The media suffer from a bad case of believing that engineering is science or is merely one of the 'lesser' letters in the beleaguering acronym STEM (see Appendix 2).

Small wonder then, that if this is all the general public have to go on, they are not keen on their children entering higher education to study Engineering. Who would? And it sounds like it is all the media's fault.

The reality might be, to rephrase a quote from the Science Media Centre (see later): **"The media will *do* engineering better when engineers *do* the media better."**

In other words, it is those of us in engineering that are to blame, not the media.

An internet trawl of professional engineering institutions reveals that many have communications or media functions, often with a prolific output of what are considered newsworthy items. The impression is that most of the output is parochial in nature, possibly of greatest interest to members of the particular PEI. Often contact details are given, should external media bodies require further information. That assumes that external media bodies know that the items are there and, with some 40 engineering PEIs, that is an unrealistic expectation.

Here are just three examples of problems that exist and give an indication of the reasons that the public is uninformed or misinformed about engineering. First, back in 2016, the BBC introduced a new TV series on BBC2 entitled *Inside the Factory* fronted by celebrity presenter Gregg Wallace (a former grocer) with presenters Cherry Healey and Ruth Goodman. The series still continues with new episodes. As the title implies, each one-hour programme features the production process for a particular item. Gregg Wallace takes the viewer from 'goods received' and the input of component parts or ingredients, through the entire manufacturing process, to 'goods out' where the completed products are loaded for distribution. Gregg gives the main commentary on camera as he meets people engaged in the various parts of the process, whilst Cherry gives short accounts of related points of interest, and Ruth provides mainly historical perspectives. The series has been tremendously successful, capturing the imagination of audiences for each episode of 3 million viewers about household-named products, and extended to five series to date. Briefly the topics covered in individual episodes to date have included most of the items in many people's grocery trolley (such as bread, chocolate and potato waffles) as well as other everyday items like beer, pencils, mattresses and Le Creuset casserole dishes. There were also three Christmas specials on food and novelties. In all, 33 hours of viewing of the results of manufacturing and production engineering in areas familiar to the general public, young and old. All the wonders of that particular (and most important) engineering discipline are there to behold – including robotics, AI and photography in high-speed defect rejection, control systems, bulk material transport, and so on. What is witnessed includes chemical engineering (food engineering) as well, of course. And yet, the words 'engineer' and 'engineering' are hardly heard and, when they are used, they relate mainly to operators and maintenance. Specifically, there is next to no reference if any to the fact that the technology witnessed was created, designed and brought into operation by professional engineers and technicians in production and manufacturing engineering – which is currently nose-diving in student engagement as shown in Fig. 9. What a missed opportunity![79]

[36] feweek.co.uk/2019/12/01/perceptions-of-engineering-hold-the-sector-back/

[36] www.raeng.org.uk/RAE/media/Grant-applications-and-guidelines/Summary-of-research-into-public-perceptions-of-engineering.pdf

[36] www.raeng.org.uk/publications/other/public-attitude-perceptions-engineering-engineers

[36] www.royalnavy.mod.uk/Careers/Role-finder/Engineering

[36] www9.nationalgridus.com/non_html/Engineering_WP.pdf

The second example is that of the European Organisation for Nuclear Research CERN (Organisation européenne pour la recherche nucléaire).[80] CERN is a large particle physics laboratory and is based in a northwest suburb of Geneva on the Franco–Swiss border. It is particularly known for its Large Hadron Collider (LHC) which lies in a circular tunnel 27 kilometres in circumference and as deep as 175 metres – and is regarded as the largest machine in the world. It is frequently referred to by the press, in particular following the discovery in 2012 of the Higgs boson, widely described by the media as 'the God Particle'.

The LHC is a science facility and this has led the media to refer to the staff (administrators and support staff apart) at CERN as scientists. The reality is rather different.[81] CERN employs ten times more engineers and technicians than research physicists.

The physics programme at CERN presents varied engineering challenges at the forefront of technology, from the atomic scale to the colossal. Engineers design, develop and commission the cutting-edge technology, machines and systems that the physicists need for their research. This includes: Designing radio frequency cavities to accelerate particles; the custom-built superconducting electromagnets that focus and guide particle beams; the world's largest cryogenic system that cools the magnets to a few degrees Kelvin; the world's largest vacuum system; super-fast electronic detectors; developing the world's largest computing grid; and providing the civil engineering infrastructure both above and below ground – among many others.

And yet the ground-breaking engineering work at CERN seldom gets a mention in the media, the activity at CERN invariably being attributed to science.

Incidentally, the worldwide web was born in CERN as a result of the work of Sir Tim Berners-Lee FREng, now Professor of Engineering in the School of Engineering at the Massachusetts Institute of Technology (MIT).

The other example is that of the Rosetta Mission. This space mission commenced in 2004 with the launch of the Rosetta spaceship, heading for the comet 67P / Churyumov-Gerasimenko – a journey of several hundred million miles. The purpose was to send the Rosetta 'lander', Philae, down to the surface of the comet and there to conduct scientific experiments on the environment of the landing site and also capture images. This was accomplished in September 2016. Although there were problems with the nature of the landing site, in all other respects the mission was successful, which was a tribute to some incredible, exacting and truly awe-inspiring engineering achievements[82 83 84] without which the scientific mission could not have been accomplished.

"The media needs to be informed and educated about positive engineering achievements of the present day"

Again, the media reports at the time referred to it all as science.

What is needed is an **Engineering Media Centre** which takes a proactive stance in seeking and coordinating inputs from sources such as PEIs, universities, and engineering industry (for example), anticipating their likely interest to particular audiences, and so initiating and making timely inputs to sometimes fast-changing news stories. (It may be recalled that the 2011 Fukushima Daiichi nuclear disaster reports on BBC television were initially fronted by a university research chemist until corrected by the engagement of a senior member of IChemE).

At the moment an Engineering Media Centre with such a function does not exist. There is a Science Media Centre (SMC)[85] in the UK which sees itself as "an independent press office helping to ensure that the public have access to the best scientific evidence and expertise through the news media when science hits the headlines".

The SMC has eight staff members, of which one has a portfolio that includes engineering – together with energy and environment. The Centre has a Board of Trustees of eleven people ("distinguished in the fields of science, engineering, medicine, journalism, communications, finance, law and policy") and an Advisory Committee of ten, ("from the fields of science, engineering, medicine, journalism and communications") – but it is not clear who, if any, are the people allied to engineering. The SMC derives its funding from donations, these totalling approximately £580,000 in 2018-19. Among the current donors are to be found the following with Engineering connections: CIBSE, IChemE, IPEM, IET, and RAEng. Past engineering-related donors included BCS, EngineeringUK, IFS, IMarEST, ICE and IMechE. Stated publications in engineering for journalists average just over 4 per year since the SMC's inception in 2002.

The Uff Report[86] states (para 179) "The media… needs to be informed and educated about positive engineering

[79] A particular case in point is a recent one-hour episode (about the manufacture of Le Creuset cast-iron casserole dishes) during which there was only one reference to an engineer and Wallace commented excitedly on the number of times that science had contributed to the production process.

[80] home.cern

[81] home.cern/science/engineering

[82] sci.esa.int/web/rosetta/-/35134-engineering

[83] www.themanufacturer.com/articles/baes-technology-enables-discoveries-in-space/

[84] www.baesystems.com/en/article/supporting-the-rosetta-mission

[85] home.cern/science/engineering

[86] www.raeng.org.uk/publications/other/uk-engineering-2016

achievements of the present day." Given the scale of engineering achievements as remarked on by Prince Philip, it is not clear the Science Media Centre fits the bill. There is an obvious answer to this conundrum however, and that is that **EngineeringUK becomes the Media Centre for Engineering.**

Given that the Royal Academy of Engineering has become the *de facto* body that communicates with government through the National Engineering Policy Centre[87] (an ambitious partnership, led by the Royal Academy of Engineering, between 39 different UK engineering organisations representing 450,000 engineers), **it seems quite natural that the EngineeringUK Media Centre should work under the aegis of RAEng.** By dropping the Big Bang Fair and subsuming Tomorrow's Engineers into the Academy's 'This is Engineering' initiative, this leaves EngineeringUK clear to promote engineering through media activities, funded by the £7M per year previously mentioned. It will be noted that EngineeringUK is already working with RAEng on the 'This is Engineering' campaign.

In addition, such a new body could investigate and develop marketing. Intel makes its presence known in computing equipment with an 'Intel Inside' sticker. Engineering could follow that lead by having 'Designed by engineers' stickers on a variety of products – an obvious idea, which marketing professionals would clearly want to refine. The time has come for a radical campaign. Marketing engineering through products must surely be a better approach than promoting it through websites – particularly when people do not even know that such websites exist. Whilst it is the case that the EngineeringUK 'Tomorrow's Engineers' and the RAEng 'This is Engineering' websites have attracted massive hits, such 'footfall' is not the most important key performance indicator. The meaningful KPI is that more young people have (for example) chosen to study Engineering at an HEI – and this, as we have seen, does not seem to be working with Tomorrow's Engineers. The RAEng activity is too new to be able to make a meaningful assessment at the present time – but anyway we surely are not relying solely on one initiative that might deliver – or not. Perhaps alongside 'This is Engineering' the website could be 'This is Engineering' the book – a massively illustrated tome in the style of the Dorling Kindersley publications with allocated pages to each of the roughly 40 professional engineering institutions to showcase their discipline? Then place copies in every school library in the country as well as making it available in all good bookshops.

Alongside these activities, we must emphasise the work of professional engineers; stress creativity, design and innovation; and liberate engineering and technology from the shackles of the acronym STEM.

FINDING 13
A proactive stance is needed to educate the media about engineering. Too often engineering (and the achievement of professional engineering) is ignored, or it is attributed to science or generalised to STEM.

FINDING 14
In the context of Engineering higher education and the status of professional engineers and engineering, the engineering brand is weak, with people not seeing the connection between products with which they are familiar and their engineering origins.

[87] www.raeng.org.uk/policy/national-engineering-policy-centre

WHAT NEXT?

The distilled quintessence of the major developments that have been proposed in this document are as follows:

1. Adoption of new approaches to Engineering higher education based upon aligning teaching and learning with *the process of engineering* typified by the three elements of creativity, design and innovation. This career-enduring approach will be instilled through problem-based learning studio groups and sit alongside individual 'flipped classroom' activities of 'lean learning' and 'content mastery' in subject areas not dominated by science and maths, but representative of the eclectic mix of those and other subjects that are the stuff of modern engineering – finance, economics, business, entrepreneurship and enterprise, management, quality, IT, languages, communication, marketing, sociology, sustainability, ethics, risk, philosophy, psychology, art and aesthetics, facilities, human resources, and so on. The learning will take place in a context of 'work skills' as outlined by Merriman and Finniston and articulated by 21st century employers, and will be assessed through the use of 'portfolios ' and 'profiles' relating to the PBL experiences.

   The hope and expectation is that such approaches will attract students from a much wider spectrum of interests and abilities and sit beside a smaller number of more traditional programmes that have more focus on science and mathematics – attracting those for whom this would be more appropriate.

   By providing and promoting Engineering higher education that covers a wide spectrum of interests and abilities (as seen with the A-level in Design & Technology) it is hoped to achieve a greater gender balance and reduce the huge gap that currently exists.

2. A grass-roots review of accreditation to ensure that it is fit for purpose, and that the Engineering Council quality assurance assessment of PEIs and their interpretation of AHEP meets acceptable standards and leads to appropriate corrective action, rigorously implemented, in HEI Engineering departments.

3. The creation of an Engineering Media Centre that formulates sustained proactive campaigns, developing messages that remove any doubt about the pervasive nature of engineering and its ubiquity and cultivating the knowledge and understanding of those involved.

4. "Everything not created by God is invented by Engineers": a marketing campaign is needed that confronts our consumer society with the connection of almost every product with that legacy.

The question is, of course, how would we implement these developments? Clearly, input is needed from academia, employers, professional engineering institutions, trade bodies, organisations representing under-represented groups, media organisations, students, government departments and all other areas that would be considered stakeholders in engineering and its development. However, there is the trail left on the internet by well-meaning initiatives that involved far too many people and have left nothing of their hard work and good intentions except for out-of-date websites that represent the internet equivalent of space junk or tumbleweed-strewn Wild West ghost towns. What is needed is a small steering group of 'doers' – people of sufficient standing and a reputation for getting things done – not just good for the first mile, but good for the full marathon. I would imagine in the first instance this group would be formed from the EPC (which, after all, represents those in the front line of Engineering higher education) together with RAEng and representatives from the 'big 4' PEIs and associated bodies and a few engineering employers. The steering group would initially consider its own development and devise a strategy for taking forward all aspects of paragraphs 1 to 4 above and incorporating (for example) the lessons learned from the IET/EPC initiative in 'New Approaches in Engineering Higher Education'. All this needs to be done in a timely manner. Change needs to be done expeditiously or stakeholders become bored and conservative.

FINDINGS & RECOMMENDATIONS

FINDING 1
Whilst the number of international students graduating on Engineering & Technology programmes has increased over the 14-year period from 2005/6 to 2018/9, the E&T market share of the total number of international graduates has fallen.

RECOMMENDATION 1
A market survey should be carried out to explore the nature and attractiveness of engineering programmes available in Australia and the US, and also from the increasing number of European institutions offering programmes taught in English. Are we making enough of PBL, CDIO, flipped classroom approaches?

The British Council has an excellent promotional website covering all subject areas, and with videos. Is the engineering offer sufficiently up to date?

FINDING 2
Despite a huge number of initiatives in schools and colleges over the reported 14-year period to increase the number of young people in Engineering higher education, there has been no significant increase in the proportion of UK-domiciled Engineering & Technology graduates.

RECOMMENDATION 2
An honest reassessment needs to be made of the efficacy of the initiatives taken. The reality has to be that initiatives that have not resulted in a significant increase in the proportion of UK graduates that qualify in Engineering & Technology should be abandoned and the considerable financial and human resources involved should be deployed elsewhere.

FINDING 3
Examination of graduate numbers across all 19 JACS subject areas over the period reveals quite dynamic behaviour with both losses and gains in market share reflecting, *inter alia*, regulation, popularity, available funding and institutional marketing strategy.

RECOMMENDATION 3
Research is needed into the effectiveness of bursaries versus fee discounts in recruitment to Engineering; the availability of scholarships and other awards (and their duration); the relative popularity of the MEng versus the BEng; and the desirability or otherwise of thick and thin sandwich schemes and their relationship to apprenticeships.

FINDING 4
The skills crisis in engineering graduate numbers is unlikely to be solved by continuing or increasing outreach and intervention strategies in schools and colleges. There is a need for different approaches to increase the appeal of E&T university programmes.

RECOMMENDATION 4
In the spirit of raising awareness, there is an argument for some local extra-curricular activity relating to the world of engineering.

In doing this, it is important to get away from the incorrect notion that engineering is all about the application of science (particularly physics) and maths – with more emphasis on the creativity, design and innovation (bringing to market) of artefacts with which young people will be familiar – phones, televisions, cars, bridges, clothes, food, planes – and so on. We are looking to provoke wonderment and awe. Building model bridges with straws and carboard boxes simply trivialises engineering.

FINDING 5
There is an urgent need to reverse the severe downward trends in the popularity of degree programmes in Electrical & Electronic Engineering and Production & Manufacturing Engineering – both subject areas of global economic importance.

RECOMMENDATION 5
There is indeed an urgent need for a study of the circumstances that have led to the rapid decline in graduate (and hence student) 'market share' of Electrical & Electronic Engineering and Production & Manufacturing Engineering. Historically, these areas were the province of the Institution of Electrical Engineers (IEE), which joined with the Institution of Incorporated Engineers (IIE) in 2006 and morphed into the Institution of Engineering & Technology (IET). Interrogating the search engine on the IET website reveals nothing of the fundamental place that these important engineering areas once held in the IEE. A pessimistic view might take this to suggest that the IET no longer represents the professional home of Electrical, Electronic, Production or Manufacturing Engineers – and yet there is no other home available. But the root cause must lie elsewhere: why are young people turned off these important subjects? We need to know and to take remedial action. Clearly, trade bodies such as Make UK (for Production & Manufacturing Engineering) and the UK Electronics Skills Foundation have a role to play.

FINDING 6
Despite huge efforts to rectify the disparity in the gender balance between female and male graduates in engineering and technology for over at least a century, the facts reflect a gross under-representation of women in engineering. New thinking is required.

RECOMMENDATION 6
The apparent difficulties faced by WES, WISE and other bodies devoted to counteracting the under-representation of women in engineering are further frustrated by the fact that many girls' schools do not enter their students for Physics A-level. Moreover, the insistence in the assertion that preparation for an engineering degree is best served by A-levels in Physics and Maths creates a further disincentive (see Finding 7).

FINDING 7
There is a disjunction between the proportion of women that engage with Design & Technology A-levels and those that show an interest in engineering degrees. This might suggest a way forward.

RECOMMENDATION 7
The development of engineering degree programmes globally where the focus is on problem-based and project-based learning, and that learning is in terms of creativity, design and innovation, sends the signal that Engineering higher education is bifurcating. Alongside the classic 'Engineering Science' courses are appearing the new approaches that might be termed 'Design Engineering'. Such courses embrace many of the eclectic list of topics that have been mentioned in this document and are typified by the 'word cloud' of Fig. 15 which reflect the typical curriculum topics for A-level Design & Technology. Noting that many females (at least a third of the D&T cohort) have embraced the subject at A-level (and indeed have outclassed the achievements of male students), it seems not unreasonable that such students might engage with the new Design Engineering programmes. The possibility deserves further investigation.

FINDINGS & RECOMMENDATIONS

FINDING 8
There is substantial evidence that parents, families, those in Whitehall and Westminster, teachers, and indeed society in general – all who have great influence over the careers of young people – are ill-informed about the nature of engineering and the nature of engineering higher education.

RECOMMENDATION 8
We need an attitude change among those of us who are qualified and work as professional engineers. We should not miss an opportunity to correct false impressions about engineering and we should seize every opportunity to pass on Prince Philip's message that "those things not invented by God were invented by professional engineers". We need to make our presence felt and we need to lobby (if of Chartered or Incorporated or equivalent status) that we be referred to as 'professional engineers'. The status of engineers has long been a troubling feature of the professional engineering community and some have adopted FEANI registration which confers use of 'Eur Ing' as a pre-nominal, which serves as another opportunity to confuse the public. Society understands that 'professional' means something special ('professional footballer' is but a starter for comparison).

FINDING 9
The evidence is that over-stressing Science (particularly Physics) and Maths does a disservice to attempts to interest young people in Engineering higher education.

RECOMMENDATION 9
More should be made of the other subjects relevant to modern engineering – including creativity, design, innovation, finance, economics, business, entrepreneurship and enterprise, management, quality, IT, languages, rhetoric, marketing, sociology, sustainability, ethics, risk, philosophy, psychology, art and aesthetics, facilities, and human resources and so appeal to a far wider range of student interests and backgrounds.

FINDING 10
Engineering higher education should not be seen as the accumulation of knowledge (typified by courses in science and maths leading to engineering topics), but as engagement with *the process of engineering*.

RECOMMENDATION 10
For many graduates, it is suggested that the 'linear curriculum' of science and maths leading on to Engineering does not provide the long-term skills needed in real engineering. Little of what is learnt is used (since engineering is not actually the practical application of science and maths) nor is it relevant in a world of rapid technological change. The *process of engineering*, on the other hand – involving creativity, design and innovation as the main activities in taking a customer requirement through to practical realisation – provides a lasting skill set throughout an engineer's career.

FINDING 11
Engineering higher education programmes should represent the convergence of a number elements: The fundamental and enduring principles and standards extolled by Merriman and Finniston; the statement of these standards expressed by AHEP; the interpretation of AHEP by professional engineering institutions for their subject disciplines in their accreditation activities; and the compliance of academic departments in higher education institutions with those accreditation requirements.

There is clear evidence that there is often a disjunction between employers' needs and higher education's provision in this regard.

RECOMMENDATION 11
The IET/IEE has been publishing its *Skills and Demand in Industry* reports since 2006 following consultation each year with literally hundreds of companies. The reports make clear that there are a number of areas that employers find wanting despite their apparent inclusion in the Engineering Council's AHEP requirements. The problem appears to emanate somewhere between PEIs' interpretation of AHEP for their engineering discipline, the PEI accreditation process itself and the HEI engineering departments actually and successfully implementing what they suggest it is that they should do. This points to the need for an independent review.

FINDING 12
The world is changing, and the world of Engineering higher education with it. In the UK, to attract more young people into the profession we need a radical reassessment of our engineering higher education programmes and of the measures that need to be taken to assure their delivery.

RECOMMENDATION 12
There are stories that in Russia immediately after WWII all university engineering lecturers would be teaching the same topics across the country at 10am on Thursday morning. While those are probably apocryphal, it was the case that for many years UK universities had static curriculum structures, albeit with differing emphasis from university to university in particular subject areas. All students on a particular degree course had the same timetable. Modular course structures changed that, with students in the same cohort having different timetables within the same discipline. We have learnt how to deal with that in terms of assessment and organisation. Now comes a bigger challenge.

With more universities globally using problem-based and project-based learning approaches and students working in groups, having different backgrounds and making different contributions to their group project work (as would happen in industry), different assessment techniques are required. Going out are conventional examinations; coming in are assessment of portfolios and profile statements. Gone are the days of assessing particular subject knowledge, but coming in is the requirement for evidence of a student's engagement with *the process of engineering* – of creativity, design and innovation and their flexibility in learning just enough to get a problem solved.

Current accreditation approaches cannot deal with such developments, and AHEP will need to be completely rethought. If we want more students with a wider spectrum of backgrounds embracing Engineering higher education and swelling the number of graduate engineers, this is the price that must be paid.

FINDINGS & RECOMMENDATIONS

FINDING 13
A proactive stance is needed to educate the media about engineering. Too often engineering (and the achievement of professional engineering) is ignored, or it is attributed to science or generalised to STEM.

RECOMMENDATION 13
For too long professional engineers have moaned about the misunderstanding of engineering in the media. For too long have they complained about the hopelessness of the situation yet have been content to do nothing about it – or for too long have they suggested that the solution might be to have an engineer in *Coronation Street* or *East Enders*.

A proactive stance will need the profession to hammer away at media commentators (and also politicians and government bodies) with the facts about engineering and revile them for the damage that they are doing to the economy and its sustainability by misrepresenting engineering.

Associated with that is the need for a total repudiation of the acronym STEM which has done a gross disservice to engineering and technology (see Appendix 2). We need to promote engineering in its own right.

It is suggested that EngineeringUK would be an ideal body to take on this role. It already has a strong brand with its biennial publication on the *State of Engineering* and it is well known for its engagement with engineering in general. Its current involvement with the Royal Academy of Engineering in the 'This is Engineering' campaign gives evidence that the two bodies can work together and its access to some £7M per year give substantial resource for what needs to be a major undertaking – taking the place of The Big Bang Fair and associated activities for the time being.

FINDING 14
The engineering brand is weak. People do not see the connection between products with which they are familiar and their engineering origins.

RECOMMENDATION 14
We need a marketing campaign – a judiciously constructed strategy to bring the words 'engineer' and 'engineering' – (and particularly professional engineering) to the attention of the public.

Some of it will be subtle – for example campaigning for the Science Museum to be renamed the 'Science and Engineering Museum'; for the House of Commons 'Science and Technology Committee to become the 'Science and Engineering' Committee; for the Government to be advised by a Chief Engineer as well as a Chief Scientist.

A less subtle approach might involve informing the public in very public ways that their purchases, or facilities, or services are the work of engineers. How many know that their mobile phone, their television, their car, their fuel, food, drink, water, electricity, trains, aeroplanes, ships, bridges, roads, are the realisation of the work of professional engineers?

APPENDIX 1
A WORD OF CAUTION

A word of caution regarding mathematics is appropriate here. A straw poll of practising professional engineers reveals that many of them seldom make direct use of high-level scientific or mathematical topics (perhaps with the exception of statistics). Today's engineers make extensive use of computer-aided design (CAD) simulation tools in their work, often mounted on fast and flexible hardware platforms. However, it is folly to put absolute trust in these tools, since they have limitations. For example, computer-aided circuit design software makes considerable use of numerical integration algorithms. It can be shown theoretically that with the exception of one simple (and relatively inaccurate) approach, all other NI algorithms have a behavioural characteristic whereby they *might* predict a stable engineering system to be unstable and *vice versa*. The construction of such tools thus requires engineers with a considerable grounding in mathematics. Students with such interests (and this is but one example) might be better served by an Engineering Science degree course than the approach based on creativity.

APPENDIX 2
STEM

The acronym STEM – a broad term used to group together the academic disciplines of Science, Technology, Engineering and Mathematics – trips off the tongue so easily. Yet it can do a disservice to Engineering – having become in many quarters a short-hand for Science. To make matters worse, the 2018 Department for Education paper on the *Next generation of young people gaining the skills Britain needs*[88] states, "We define STEM subjects as: Biology; Chemistry; Computing; Mathematics (including statistics); Further Mathematics; and Physics." No wonder that DATA (the Design & Technology Association) that promotes and supports A-level courses in Design & Technology was apoplectic in its response.[89] "This definition defines STEM as essentially being Maths and Science (including Computer Science) with absolutely no mention or recognition of the importance of Design & Technology or Engineering. This definition has come without any consultation or warning of any sort and obviously needs to be explained."

And what of the 'T' and 'E' in STEM? Many will ask what defines Technology and how does it differ from Engineering? The Royal Academy of Engineering comes to the rescue here[90] on its 'This is Engineering' website with the simple statement 'Tech is Engineering', although this is unfortunate in that it uses the abbreviation 'Tech' for technology, an abbreviation appropriated by the media for companies that use technology – such as Google, Facebook and Amazon. Most would agree that technology is the product of engineering, although it is often used as a synonym of engineering (and unfortunately so often coupled with science – as in 'science and technology' – with no mention of engineering).

In short, the acronym STEM does not assist in an understanding of the constituent areas and their relationships and must be held guilty as one of the confusing aspects of the quest to increase the number of engineers in our society. The Executive Summary of *Engineering skills for the future: The 2013 Perkins Review revisited*[91] states that "Despite significant effort, the available data strongly suggests a shortage of engineers and a worrying stagnation of young people opting to study post-16 the subjects that lead to engineering careers. The historic focus on STEM as a concept may be part of the issue."

It would seem clear that the acronym STEM is not the best platform from which to showcase and promote engineering. If we wish to do that, then we should just talk about engineering and not dilute it by using the acronym STEM.

[88] www.gov.uk/government/news/next-generation-of-young-people-gaining-the-skills-britain-needs
[89] www.data.org.uk/news/dfe-definition-of-stem-subjects/
[90] www.thisisengineering.org.uk/what-interests-you/technology/
[91] www.raeng.org.uk/perkins2019

GLOSSARY

A-Level	GCE Advanced Level
AHEP	Accreditation of Higher Education Programmes
BEng	Bachelor of Engineering
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacture
CDIO	Conceive – Design – Implement - Operate
CEng	Chartered Engineer
CERN	European Organisation for Nuclear Research
CIBSE	Chartered Institute of Building Service Engineers
D&T	Design & Technology
DATA	Design & Technology Association
E&T	Engineering & Technology
EA1	Engineering Application 1 (introduction to fabrication and use of materials)
EA2	Engineering Application 2 (application of engineering principles)
EAB	Engineering Accreditation Board
EEF	Engineering Employers Federation
EngTech	Technician Engineer
ERA	Electrical Research Association
ETB	Engineering and Technology Board (now trades as EngineeringUK)
Eur Ing	European Engineer
FEANI	European Federation of National Engineering Institutions
GCE	General Certificate of Education
HEI	Higher Education Institution
HESA	Higher Education Statistics Agency
ICE	Institution of Civil Engineers
IChemE	Institution of Chemical Engineers
ICTech	Information and Communications Technology Technician
IEE	Institution of Electrical Engineers
IEng	Incorporated Engineer
IET	Institution of Engineering and Technology
IMarEST	Institute of Marine Engineering, Science and Technology
IMECHE	Institution of Mechanical Engineers
IPEM	Institute of Physics and Engineering in Medicine
IT	Information Technology
JACS	Joint Academic Coding System
JBM	Joint Board of Moderators
KISS	Keep It Simple, Stupid
LHC	Large Hadron Collider
Make UK	Successor to the Engineering Employers Federation (EEF)
MEng	Master of Engineering
NAE	National Academy of Engineering (US)
NCUB	National Centre for Universities and Business
NMITE	New Model Institute for Technology and Engineering
PBL	Problem-Based Learning (Project-Based Learning)
PEI	Professional Engineering Institution
QAA	Quality Assurance Agency
RAEng	Royal Academy of Engineering
SKOPE	Centre for Skills, Knowledge and Organisational Performance
SMC	Science Media Centre
STEM	Science, Technology, Engineering and Maths
TEDI-London	tedi-london.ac.uk
UCAS	Universities and Colleges Admissions Service
UKESF	United Kingdom Electronic Skills Foundation
UK-SPEC	United Kingdom Standard for Professional Engineering Competence
WES	Women's Engineering Society
WISE	Women in Science and Engineering

ENGINEERING ENGINEERING A PROVOCATION