An Investigative Review: How Well Does the Higher Engineering Education Curriculum Align With the UK's Economic and National Goals?

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Abstract

It is generally believed that there should be a close alignment between a country's national and economic goals and the curriculum delivered in its educational institutions. Historically in the UK, engineering and manufacturing has provided the largest contribution to the economy. It could be argued that at that time, the skills required to work in the industry were relatively rudimental and this was reflected in the how engineers were trained, which initially adopted an apprenticeship style of teaching and later, with the increase in university recruitment, was predominantly teacher-focused and technical-content driven. Advancements in technology, medicine and other fields have brought about the need for a new, flexible type of engineer with skills that go beyond those previously defined. During the time of these advancements, the UK has seen its engineering sector decline economically, which has led to the re-addressing of the engineering curriculum. However, with the UK aiming to significantly increase the contribution of the engineering sector towards the economy, it begs the question - how well does the engineering curriculum now match up with the UK's economic and national goals? This literature review-based study will explore the extent of the alignment of the UK's economic goals with the engineering curriculum in UK universities. It will begin by looking at the historic alignment and subsequent changes to society before discussing the current state of the engineering curriculum. Finally it will assess the economic aims of the UK and provide a thorough discussion on how the alignment could be improved.

Keywords: Engineering Education, Engineering Industry, Engineering Economic Contribution

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Introduction – The Evolution of Engineering and the Economy in the UK

In order to understand the importance of engineering and manufacturing to the UK's national identity, it is important to reflect on how this sector has contributed to the making of the UK and its global economic positioning. By understanding this, the rationale behind the UK's current economic goals can be better understood and mechanisms by which these goals can be achieved can be determined via the exploring the state of the engineering curriculum globally.

British manufacturing and engineering as it is known today began with the Industrial Revolution in the late 1700s. Prior to this, manufacturing occurred mostly in small workshops and with the use of hand tools as opposed to machinery (White, 2002) During that time, training and education usually occurred via apprenticeships and learnerships, which typically took a long period of time of at least 7 years or more (Augustyn, 2010). Industrialisation in the UK led to a significant shift from an agriculturally-centered economy to a predominantly machine-powered one and altered attitudes towards training and education. The advancements in engineering technologies and the emergence of factories led to the establishment of systemisation and mass production of goods and gave rise to what is now termed as the manufacturing and engineering 'industry.' Due to societal needs at the time, the main outputs of manufacturing were iron, steel, textiles and chemicals and subsequently the rise of the coal industry, which led to growth in the transportation industry and the construction of railway networks that allowed manufacturers and engineers to transport goods beyond the UK (McFadden, 2018). This modernisation brought forth the need for division of labour and specialised skills. Less-skilled workers were still needed for jobs not requiring formal instruction, however skilled engineers were typically those that had acquired technical expertise from institutions such as universities and therefore automatically qualified for advanced positions in the industry, leading to the introduction of the system of upgrading and vocational careers. Resultantly, in the first half of the 1800s, the UK's export value increased five-fold. At that time, the UK's engineering and manufacturing sector was the biggest globally and the UK were recognised as the *most technologically advanced* country in the world (Maven, 2009).

The beginning of the 20th century saw Germany and the US overtake the UK as global leaders in engineering and manufacturing and this period became known as the second industrial revolution. However despite this, the sector still accounted for approximately half of the national output. In this period, proceeds from oil and gas contributed significantly to the UK's economy (McFadden, 2018). The end of the Second World War saw a significant decline in the UK's engineering and manufacturing sector, both in terms of proportion to national gross domestic product (GDP) and employment and as the UK began to import more goods, the economic contribution of the service industry began to rise rapidly. Furthermore, over the past 30 years, a number of previously British-owned engineering and manufacturing companies were sold to overseas companies, leading to widespread cuts and closures in the sector.

More recent economic statistics provide an unpredictable but optimistic outlook for the UK. At the beginning of the last decade, engineering and the manufacturing sector accounted for 12% of the UK's national output and employed just over 8% of the British workforce and by 2014, the sector accounted for 44% of British exports, which rose to over 50% by 2019 (Scott, 2017). In engineering and manufacturing, as a share of the national GDP, the UK ranks 5th globally behind China, the US, Japan and Germany. Currently, the UK's major engineering industries are in pharmaceuticals, food, drink and aerospace engineering, a vast change to the main manufacturing outputs during the industrial revolution and this shift has led to the need for a new type of engineer (Sacks, 2016).

The link between technical expertise in engineering and employability potential provided an impetus for more people to seek formal education in universities. The culture of training and education in this era was teacher-centric so naturally, the curriculum in universities was heavily technically focused and taught with teacher-centered approach.

The UK has gone from being the sole global leader in the engineering and manufacturing to seeing its gradual decline in the sector. This begs the question, what is the current state of affairs concerning the curriculum and what needs to be re-addressed to aid alignment?

The Current State and the Re-addressing of the Curriculum

Advancements in social activity, such as the influence of technology on lifestyle choices, pressures on healthcare due to the emergence of new diseases and the need for advanced therapies and a steady increase in population and immigration has led to the need for increased food supply, energy supply, transportation and housing, which have consequently impacted on the environment. Engineers as decision makers and solution creators are now much more closely and directly linked with societal changes and therefore the type of engineer produced today needs to align with that and this links directly with how engineers need to be educated and trained in today's world.

Over the past 20 years, the requirement for broadening of the curriculum has been highlighted by a number of stakeholders including, accreditation bodies, professional institutions, industry and government. All have emphasised the need for a reform in engineering education that encompasses a whole set of transversal skills, from the ability to think critically, to working in teams, socio-economic considerations, sustainability and ethics, all built on deep technical understanding (Mitchell *et al.*, 2019). The past decade has seen an emergence of engineering education research (EER) as a means of re-addressing the engineering curriculum and how engineers of today are being prepared for societal and environmental changes (de Graaff, 2017).

A number of world leading institutions have used EER outcomes to inform practice in the classroom and reform their curriculum. Whilst it is important to bear in mind that the requirements of an engineer may differ slightly from nation to nation, there is a general trend that shows that integrated, multidisciplinary, student-centred curricula is the trajectory. The Singapore University of Technology and Design incorporates this into their curriculum via multidisciplinary design projects, the purpose of which is to integrate and contextualise learning across years of study as well as across modules (SUTD, 2011). This change has had a ripple effect across a number of engineering institutions across the nation and the success of this change has led to Singapore achieving an Engineering Index score of over 60% which places them amongst the top 5 in all of Asia and the Oceania region (Cebr, 2016). One of the most notable programme reforms was implemented by Charles Sturt University - Engineering, Australia. This five and a half programme incorporates 18 months on-campus learning which is built around a number of project-based challenges and proceeded by four years of work-based education, off-campus. The technical and skills-based knowledge is delivered online and students are able to independently access it as and when needed (CSU, 2018). The successful implementation of this programme and similar programmes across

Australia in efforts to address their national goals has led to Australia being considered as an emerging leader in EER (Graham, 2018).

The US is globally considered to have the best institutions for engineering education research and have proved that this research has directly impacted on education reform. Olin College, Massachusetts Institute of Technology (MIT) and Purdue University are consistently ranked in the top 5 for EER, with Purdue University being the first ever university to open a School of Engineering Education with undergraduate, post-graduate and doctoral student intake in 2004 (Perdue-University, 2018). As a result of their research, all have adopted a 'project-centric' approach to their engineering curricula and although the strategy of implementation differs slightly from institution to institution, all focus on the ability to apply knowledge with the demonstration of both technical and professional competence. MIT in particular allow students to choose a 'thread' of interdepartmental courses, which more often than not, means that projects undertaken are multidisciplinary. The curriculum has been revised to focus on 'ways of thinking' and the demonstrated ability to apply knowledge based on ethics, self-learning, critical thinking and creative thinking (MIT, 2017).

The national impact of these successes is that the US by far surpasses all other nations for the number of engineering institutions in the world's top 100, of which 31 are US-based and 4 are in the top 5 according to the *Times Higher Education* World University Rankings. Economically this has meant that for more than half a decade, the US has been ranked the highest for average wages and salaries for engineers as well as being ranked the highest globally for engineering research impact and financial contributions (Cebr, 2016).

Since the establishment of this research area, there has been a gradual but recognizable shift in the understanding of good pedagogic practice in the UK and its application to engineering. A number of centres and research groups have been set up with a sole focus on engineering education; such include: Manchester Science and Engineering Education Research and Innovation Hub, Aston Engineering Education Research Group, Kings College London Centre for Research in Education in STEM, University College London Centre for Engineering Education and a few others (Hauke, 2014). With that said, there is a disconnect between the research in this area and the implementation of its findings in the curriculum. A cyclical model by which research and practice continually influence and develop one another has been proposed by Jesiek et al. (2010) and Borrego and Bernhard (2011), however very few have applied this model by reporting on how the use of their research has had impact and wide-scale application across the engineering curriculum as a whole within their institutions.

In 2014 however, the UCL Faculty of Engineering Sciences became the first research intensive, high-ranking UK institution to successfully implement a complete revision of engineering education across the majority of the faculty via the introduction of the Integrated Engineering Programme (IEP). In this programme all students enter through their disciplinary specialisms but share a common framework that integrates discipline-specific content (technical) with professional skills, design, project and problem-based learning along with a multidisciplinary and student-centred pedagogy throughout the student's degree (see Figure 1).

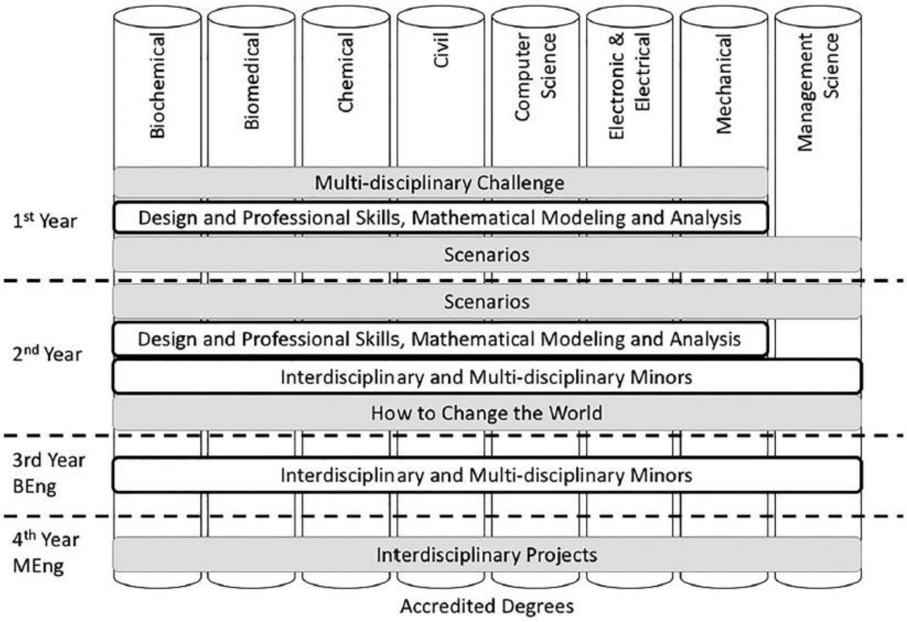

Figure 1: Overall Structure of the Integrated Engineering Programme.
From Mitchell et al. 2019

The programme was designed to directly address the concerns raised by various stakeholders in efforts to produce graduate engineers with the capabilities of tackling global issues of today and beyond. Students are trained in areas that develop effective communication with technical and non-technical specialists, safety and risk, critical and creative thinking, design, decision making and teamwork. Since its implementation, it has seen the graduation of three cohorts of engineering students so far, both at bachelors and Masters levels.

Since then a number of UK institutions have implemented similar revisions to their practice but not on the same scale as UCL. The evidence suggests that if the UK is to remain economically competitive within engineering and possibly see its former glory days, more institutions need to implement these revisions across the engineering curriculum as a whole and furthermore, lessons should be learned from the UK's main global competitors.

How Can the Alignment Be Improved?

The UK is currently ranked 14th in the engineering sector globally according to the Engineering Index, which takes into account several factors such as research, gender balance, engineering employment, wages and salaries, among other factors (Cebr, 2016). Whilst the UK boasts high research impact and digital connectivity, it has one of the lowest proportions of female engineering graduates and overall gender balance in engineering. It could be argued that this is a contributory factor when considering that the number of people studying engineering and the quality of engineers with a wide range of skills to meet societal demands continues to be problematic and stands to reason as to why the UK finds itself in its current position.

Women make up 47% of the overall UK workforce however only 12% of those work in engineering occupations (Neave *et al.*, 2018). Evidence suggests that this underrepresentation could be systemic and one that is formulated in early-stage education (Archer, Moote and MacLeod, 2020). A survey conducted by *Engineering UK* in 2018 reported that only 34% of girls aged 7-11 expressed interest in becoming an engineer when they were older, compared to almost 60% of the boys their age. By the ages of 16-19 this number had reduced to 25% for the girls, whilst this number was more than double the proportion for boys of the same age. Furthermore, the evidence suggests that there are strong gender differences in educational choices. Statistics show that only 27% of girls made STEM subject choices at A-level compared to 46% of boys and worse still, only 16% of engineering students graduating at first degree level were female. Post-education, there are further leakages in the labour market, leading to the current figures for women in engineering occupations. In a similar vein, statistics show that whilst 25% of engineering students are of a BME background, they only account for 8% of the UK engineering workforce (Neave *et al.*, 2018).

A number of initiatives have been set up as a means of closing the gap of underrepresented groups in the workplace. With particular focus on gender, the Government Equalities office aims to generate a 20% increase of females entering STEM higher education studies, which if successful may in turn lead to the UK rising above Italy and Germany in female workplace recruitment (Cebr, 2016, Neave *et al.*, 2018). To help implement this, a number of initiatives have been rolled out in an attempt to support more girls into engineering. These include organisations such as Women into Science and Engineering Campaign (WISE) and Women Engineering Society (WES) who work to promote visibility and representation mainly via promotional campaigns, visual marketing and inspirational activities such as talks and presentations (Marsh, 2010). There are also a number of stakeholders such as Government agencies (e.g. Teach First, Association of Science Educators), Engineering bodies (e.g. Royal Academy of Engineering, Engineering Council) as well as employers and bodies all with individual initiatives towards closing the gender gap in engineering in the UK. For example, the Careers & Enterprise Company has set an agenda and strategy on increasing the number of STEM A-level subjects taken by girls, whilst other organisations and bodies focus on primary education and some on higher education (Department-for-Education, 2014).

It should be noted that whilst the initiatives are encouraging to see, there is evidence to suggest that there are too many initiatives (600+) and a lack of evidence of impact in order to understand what effect these initiatives are having on the target groups (Neave *et al.*, 2018). A thorough assessment of the efficacy of these engagement activities is needed and closer interactions between the government, industry and the educating community are key in improving the UK’s record on diversity and inclusion.

Another way industry could play a role in improving the UK’s alignment is through the embedding of work-based education concepts into the curriculum. At the SEFI 47th Annual Conference, 2019 (European Society for Engineering Education), a group of university students challenged a panel of industry experts from various engineering fields on the following topic – “*Should engineering students be treated as engineers*?” The panel experts each presented for 5-10 minutes on the necessary underlying competences needed by today’s engineers and the need for a change in traditional university attitudes. The industrial experts suggested that due to the ever-changing societal demands, universities needed to become, what could only be interpreted as, pseudo-engineering cooperations. This change in attitude would enable engineering students to be treated as (learner) engineers and would better align with workplace practice and help reduce the skills shortage. What this panel lacked was a university educator’s perspective addressing feasibility and what this would mean in practice.

There are a number of issues with the feasibility of this approach, mostly concerning the time and resource constraints of an academic curriculum and career cycle in the UK. One approach on addressing this has been more emphasis on work placements and internships from as early as first year of undergraduate studies. In other areas such as social sciences and the arts, work placements and internships are integrated into the curriculum in a number of institutions and make up a higher contribution towards the final degree classification (Hurst and Good, 2010, Newman *et al.*, 2007). Knouse, Tanner and Harris (1999) found that upon graduation, business students that completed regular internships as part of their programme obtained jobs more readily and were more easily incorporated into the workplace. There is a growing urge from accrediting bodies for the UK engineering curriculum to follow suit given the dynamic nature of societal demands on technology and the environment and it may further serve as an approach to close the transition gap and between university and the workplace as well as reducing the skills shortage.

Not unrelated, another route into engineering that could aid to close the skills shortage gap and in so doing, help improve the UK's alignment is apprenticeships. In the recent past, the *Wolf Report* 2011 reported the low qualification value of many apprenticeships and because of that, a lack of alternative routes for learners to navigate towards attaining high value engineering qualifications. However as of 2014, government associated bodies have been working with a number of 'trailblazer' employers to develop new and reformed apprenticeship standards. These standards contain assessment plans produced by the employers and then collated and published by the government for training companies and employers to use. 355 standards were ready as of November 2017, of which 165 have been approved for delivery, leaving 149 remaining. These standards highlight knowledge, skills and professional conduct required for vocational occupation and well-valued qualifications are now mandatory if learners are on the degree apprenticeship path (Neave *et al.*, 2018). It is still too early to learn to know the extent of effectiveness of this government sponsored initiative, however it is a positive step towards closing the skills gap.

A further improvement to the UK's alignment lies in understanding how changes in societal needs have contributed towards the emergence of new engineering fields and allowed for the adaptation of existing fields. With the creation computers, an example of a relatively recent emerging field is computer software engineering. July 2008 saw the release of the first mobile 'app' and since then, the need for engineers in this area has skyrocketed (Strain, 2015). According to *The Bureau of Labour Statistics*, a 17% increase in software engineering employment is expected between 2014-2024 and the growth rate for app developers is yet higher at 19%. Another area of growth is within the biopharmaceutical industry. The global market for pharmaceuticals is projected to reach $1.5 trillion by 2023 and with medicine becoming more personalised, there has been an emergence of the area of biochemical engineering, an interdisciplinary field stemming from a combination of chemical engineering and biotechnology (Basta, 2019). A little over 20 years ago, UCL Biochemical Engineering became the first department of its kind in the UK focusing on industrial biotechnology, macromolecular bioprocessing and cell and gene therapy bioprocessing to address the growing need for personalised medicines (UCL, 2020). Whilst this need continues to exist, there have been few departments dedicated to this focus, with only 2 such departments existing in the UK. If the UK are to improve its national and economic standings in this area, strategies need to be made and implemented to firstly ensure the representation of emerging fields in higher education and to ensure uptake of students and employment in these fields.

As previously mentioned, depending on the needs of a specific country, there is a likelihood that certain engineering skills far outpace the supply meaning that more engineers are required from certain disciplines than from others. According to a study by *Cebr 2016*, in

2014/15, the UK saw a total of just over 45,000 engineering qualifications obtained, of which almost a quarter were in electronic and electrical engineering (EEE). This may suggest that there is a higher demand for engineers with this expertise, however it can also be argued that there may also be an overall greater awareness of this part of the industry. Less popular choices were aerospace engineering and chemical engineering which together amassed less than 15% of degree level qualifications. This may suggest that these areas are perhaps not as well understood as EEE or that the demand for engineers with such skills is low in the UK. However, according to the *Institution of Engineering and Technology (IET)* across the sector, an average of over 50% of engineering employers reported that they are seeking new recruits. As discussed earlier, given the rise in initiatives to get people studying engineering, effective strategies that get these graduates into the engineering workforce have not been shown. In order for the UK to move forward, more clarity is needed on where the future engineering skill shortages will be.

Lastly, whilst there are many more suggestions that could be proposed on ways to improve the UK's alignment, such as questioning the UK's education system as a whole and whether an argument can be made about how early UK students specialise compared to other nations, an equally important point to highlight is related to the perception of engineering in the UK. *The Royal Academy of Engineering 2016* reported that in spite of the noteworthy impact of engineering in society, many developed countries still lack knowledge on the variety of engineering disciplines and their impact. In the UK, this lack of knowledge could be a reason behind the misconception and the broad use of the term 'engineer', which for many does not distinguish between chartered engineers and engineering technicians. Whilst some contributions of the profession to society were recognised, young people particularly lacked understanding of what an engineer's job actually is, which as alluded to earlier, likely has an impact on a young person's decision to study engineering (Cebr, 2016). A lot of work has been carried out by foundations, non-governmental organisations and private companies to improve the perception of engineers and studying engineering. Effective publicising by all stakeholders will aid in allowing the general public to see and understand the positive and significant impact that engineering has on society.

Conclusion

Historically the UK had been globally considered the most technologically advanced country but since the end of the Second World War, the UK's national and economic positioning in engineering began to decline. Since the turn of the century, the changes in societal needs for medicine, food, technology etc. has led to a rising demand for universities to produce engineering students that are well equipped to address these issues. These engineers will need to be leaders, able to create strategic vision, work well with other engineers and related fields and effectively communicate their findings with various audiences (Kerr, 2010). This posed the need to investigate how well the UK's engineering curriculum aligns with its national and economic goals and where necessary, provide recommendations on how the alignment could be improved.

The engineering curriculum is seeing a movement from traditional teacher-centred, technically-focused pedagogy to a student-centred, project-based and multidisciplinary approach. Whilst the UK makes gradual advances in this area and EER, what is clear is that many more institutions need to engage in reforming their curriculum cross-departmentally and furthermore, an improvement of research informed practice is crucial.

Whilst the evidence suggests a misalignment of the UK's goals with its current engineering curriculum, a number of efforts can be implemented so as to allow the UK to remain competitive in this fast moving industry. A range of initiatives have been introduced by stakeholders and associated organisations to encourage the uptake of underrepresented groups, particularly women in engineering as a means of addressing the shortage of engineers in the UK. Whilst encouraging, there is a lack of evidence to shows what impact these initiatives have on the proportion of females studying engineering and importantly, working within the engineering sector. It can be concluded that until such studies are carried out, a definitive link between these initiatives and an improvement in uptake cannot be made.

This report has focused primarily on university education, but it is key to note that there are other entry routes such as apprenticeships that could contribute towards the UK achieving its goals. The government have rolled out a new strategy towards improving the value of apprenticeships in the UK. If successful, it could see the uptake of a significant proportion to the population and help towards addressing the skills shortage. Questions should be asked about the UK education system as a whole and whether there is a need for early specialisation, as there is evidence to suggest that whilst technical expertise is still valued, a greater emphasis on general, interdisciplinary knowledge is emerging and appears to be more compatible with education systems in which students specialise later on, such as in the US and many parts of Europe (Murchie, 2016). Whilst the UK may not be the engineering powerhouse it once was, it still remains a global force in the sector and technologically one of the most advanced in the world and upon the successful implementation of a number of strategies mentioned in this report, there remains every possibility of the UK reaching and sustaining its national and economic target in the engineering sector.

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