Chapter

Fusion Skills and Industry 5.0: Conceptions and Challenges

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Abstract

The nature of work is changing rapidly, driven by the digital technologies that underpin industry 5.0. It has been argued worldwide that engineering education must adapt to these changes which have the potential to rewrite the core curriculum across engineering as a broader range of skills compete with traditional engineering knowledge. Although it is clear that skills such as data science, machine learning and AI will become fundamental skills of the future it is less clear how these should be integrated into existing engineering education curricula to ensure relevance of graduates. This chapter looks at the nature of future fusion skills and the range of strategies that might be adopted to integrated these into the existing engineering education curriculum.

Keywords: Digital Skills, Curriculum Development

1. Introduction

Up until the impact of the global pandemic known colloquially as Covid-19, the engineering education community and the industry sectors its graduates support had been involved in a debate over the necessary skills of an engineering graduate for some time. That debate in the UK reflected, on the one hand, the longstanding concern as, for example, the IET's annual Skills and Demand in Industry Survey [1] highlighted, an "estimated annual shortfall of 59,000 new engineering graduates and technicians, a deficit which only continues to get worse." ([1], p. 2), with 48% reporting difficulties in respect to the skills available – of these 73% attributed this to "Problem with candidates who have academic knowledge but lack workplace skills" ([1], p. 16). And, on the other hand, a response to the perceived challenge posed by some developments associated with the *4th Industrial Revolution* and prospect of Industry 5.0 that will require new, rather than additional, engineering skills [2].

Since the future is open to debate and discussion, the aim of this chapter is to present scenario-based perspectives [3, 4] on the development of global engineering education in response to them. The chapter is therefore structured as follows. It starts by offering a concise explanation of the concept of *the 4th Industrial Revolution* and its associated promise (elimination of environmental problems) and threats (automation). It then traces the emergence of Industry and Society 5.0 out of the 4IR to show their close association with, and significant difference from, one another. Next, the chapter addresses the issue of engineering and specialisation by considering the relationship between recent innovations in engineering education and current projections of new digital skill needs, and the extent to which the former will provide the foundation for delivering the latter. The chapter problematises this assumed trajectory of development by introducing the concept of *fusion skills* [5]. This concept represents an attempt to rethink the longstanding debate about the extent to which 'machines' are deployed to automate or augment human work through the deployment of AI in workplaces and occupations, by identifying eight new skills that are far more radical and far reaching than the concept of digital skills. Having done so, the chapter concludes by outlining 2 scenarios depicting different options for the development of the *engineering degree for Industry 5.0*, based on the introduction of fusion skills into traditional single subject and integrated or interdisciplinary engineering degrees.

2. From the 4th industrial revolution to industry and society 5.0

Over the last thirty years, the concept of *industrial revolution* has been elevated from its academic origins in literature addressing the economics, history, sociology and politics of technological change into mainstream media discussions and debates about the future trajectory of direction of societies. The concept that has generated most discussion in the last decade is the *4th Industrial Revolution* (4IR). The 4IR is an "umbrella" [6] concept, in other words, it packages together a number of technological developments, including recent and expected advances in machine learning (ML), artificial intelligence (AI), robotics, 3-D printing and the Internet of Things (IoT), to forecast the future direction of economic, social and technological development in the 21st century. Part of the reason the 4IR has become a commonplace term and a feature of the popular, policy and research vocabulary across the globe as a result of its promotion by the World Economic Forum [7]. The WEF – a not-for-profit organisation – is chaired by Founder and Executive Chairman Professor Klaus Schwab and is guided by a Board of Trustees made up of global leaders from business, politics, academia and civil society. It defines its mission as "committed to improving the state of the world by engaging business, political, academic, and other leaders of society to shape global, regional, and industry agendas" [8]. In the context of its mission statement, one of the WEF's concerns is to serve as a global platform for interaction, insight and impact on the scientific and technological changes that are changing the way we live, work and relate to one another.

To advance and popularise this concern, Schwab wrote in 2017 the first book to be published with the title *The 4th Industrial Revolution* [9]. Drawing, lightly, on the well-established tradition of the historical chronology of the invention of technological tools and techniques [10, 11], Schwab presents a compelling narrative about technological change. He argues it is possible to identify four distinctive phases of technological change or in his more flamboyant term "revolutions." They are summarised as follows [9]:

- The First Industrial Revolution was characterised by the use of water and steam power to mechanise production;

- the Second was characterised by the use of electric power to create mass production;

- the Third was characterised by the use of electronics and information technology to automate production.

The Fourth is however, according to Schwab ([9], p. 1–2) very different, because it is "characterised by a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres, collectively referred to as cyber-physical systems". This fusion or blurring is occurring as a result of technological breakthroughs, such as artificial intelligence, nanotechnology, biotechnology and robotics, becoming firstly, commercialised via additive manufacture/3D printing and autonomous transport and secondly, interconnected through the Internet of Things underpinned by fifth-generation wireless technologies (5G) (**Figure 1**).

There are two discernible perspectives – promise and threats – on the 4IR.

2.1 The promise of the 4IR

The underpinning assumption of the promise perspectives is that all the technological developments associated with the 4IR have one key feature in common Schwab ([9] p. 1–3): they are underpinned by cumulative and exponential developments in digitization and computer science impacting on their own development (i.e. continuous development of the next generation of algorithms and technological artefacts and services) as much as on the material and biological worlds.

The main systemic development enabled by the 4IR is the Internet of Things (IoT), that is, a network comprised of machine-to-machine communication empowered by computers that can gather and interpret information [13]. In its simplest form, the IoT will, as a result of convergence of multiple technologies such as real-time analytics, machine learning, commodity sensors and embedded systems, "connect everything with everyone in an integrated global network. People, machines, natural resources, production lines, logistics networks, consumption habits, recycling flows, and virtually every other aspect of economic and social life will be linked by sensors and software to the IoT platform, continually feeding Big Data to every node – businesses, homes, vehicles – moment to moment, in real time" ([13] p. 11). Rifkin's somewhat Panglossian vision of the IoT can be illustrated through reference to the role of 3D printing. This form of printing, which is sometimes called additive manufacturing employs, as Ford ([14], p. 171) explains, "a computer-controlled print head that fabricates solid objects by repeatedly depositing thin layers of material." Depending on the object to be created, 3D printing

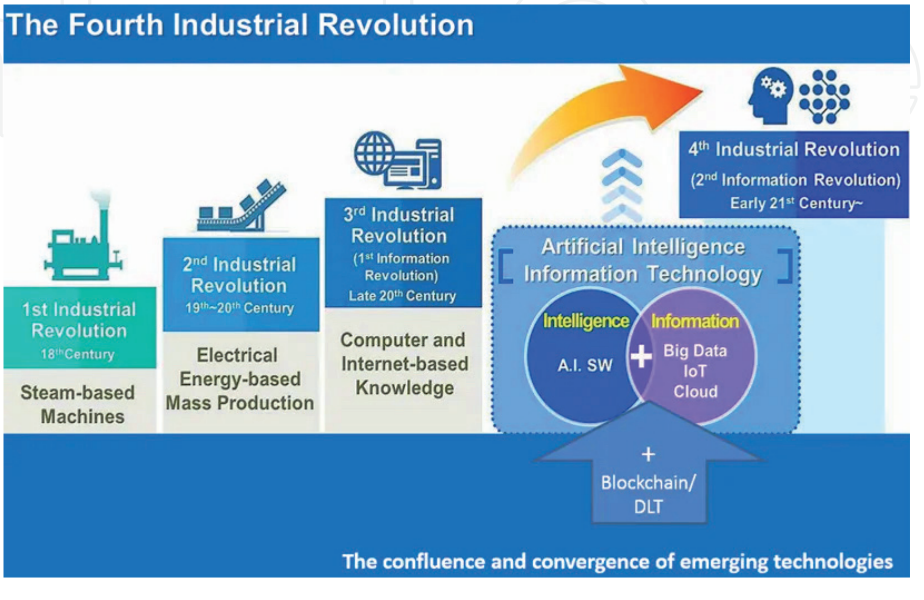

Figure 1.
The fourth industrial revolution – *Created by William Genovese on behalf of the Chinese telecommunication company Huawei [12].*

starts with a decision about which material will be used and then proceeds to builds an object into a three-dimensional shape using a digital template. Currently, 3D printing is primarily limited to applications in the automotive, aerospace and medical industries, where it is being "integrated with traditional manufacturing" ([14], p. 173). Looking to the future, it is anticipated that as size, cost and speed constraints are reduced, 3D printing will become "more pervasive to include integrated electronic components such as circuit boards and even human cells and organs" ([9], p. 17).

Turning our attention to the 4IR's potential through the use of technologies and intelligent systems design to not only restore and regenerate our natural environment, but also support a "great reset' [15] after Covid we encounter the promotion of a new natural and social Panglossian vision. At its heart is a tantalising suggestion that the 4IR can be harnessed to "build entirely new foundations for our economic and social systems [15]. This great reset would, according to Schwab, have three main components. The first would steer the market toward fairer outcomes. To this end, governments should improve coordination (for example, in tax, regulatory, and fiscal policy), upgrade trade arrangements, and create the conditions for a "stakeholder economy." The second component of a Great Reset agenda would ensure that investments, especially in AI, advance shared goals, such as equality and sustainability. Here, the large-scale spending programs that many governments are implementing, for example, the "Biden" plan, represent a major opportunity for progress. One way is to ensure funds are used to create a more resilient, equitable, and sustainable society by using AI to assist with, for example, building "green" urban infrastructure and creating incentives for industries to improve their track record on environmental, social, and governance metrics. The third and final priority is to harness the innovations of the Fourth Industrial Revolution to support the public good, especially by addressing health and social challenges. During the COVID-19 crisis, companies, universities, and others have joined forces to develop diagnostics, therapeutics, and possible vaccines; establish testing centers; create mechanisms for tracing infections; and deliver telemedicine. Imagine what could be possible if similar concerted efforts were made in every sector.

2.2 The threat posed by the 4IR

Alongside the above Panglosian vision of the 4IR, its market-focused advocates also acknowledge the possibility that it might result in a world without work. Reports from global professional service companies, such as Deloitte, Forbes McKinsey, PEW and Price Waterhouse Coopers, all contain sections contrasting the impact of emerging technologies on the labour market. At the heart of this dystopian view of about the potential outcomes of the 4IR lies the issue of *automation*. The threat that the development of new technology might pose to employment has been a subject of debate in History of Technology, Labour Economics, and Political Economy for many decades (see [16] for a recent overview). The scene was set however for the current debate among think tanks, professional service firms and researchers about the effects of automation on employment by the report [17]. Their report has achieved near totemic status as regards the forms of employment 'at risk' of automation issue because, as Frey and Osborne ([17], p. 5) note, they forecast before more or less any other researchers "what recent technological progress is likely to mean for the future of employment." **Figure 2**, using data from the Data from McKinsey Global Institute [18] gives an indication of the scale of the shift required, predicting that up to 800 million workers worldwide, approximately 30% of the workforce, may be impacted with up to 375 million needing to change occupation category as a consequence.

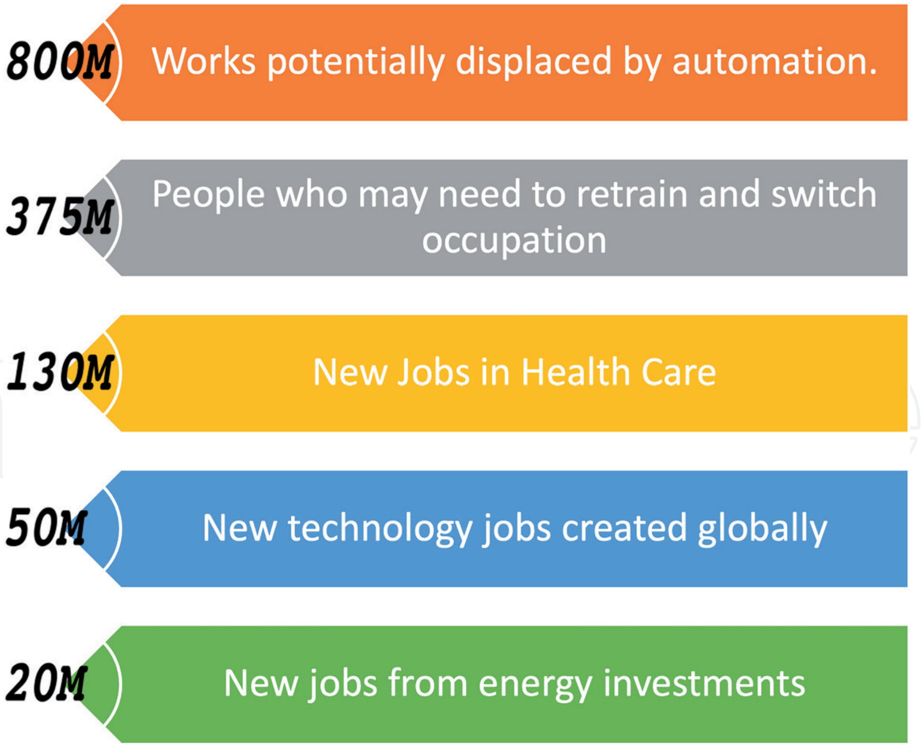

Figure 2.
The impact and threat of 4IR on employability and jobs by 2030. Data from McKinsey global institute analysis [18].

They achieved this goal by focusing on the susceptibility of jobs to computerisation in the following way. Selecting the technological advances in Machine Learning (ML) and Mobile Robotics (MR), Frey and Osborne demonstrated the ways in which such technologies are now able to perform tasks which have until recently been considered genuinely human and this state of affairs is escalating rapidly. Moreover, Frey and Osborne concluded based on this possibility and their prediction employers would automate work processes that this enhanced technological performance was no longer confined to routine tasks as has been the assumption of most studies in labour economics in the past decade (see [19] and [20] for reviews of the literature). It is increasingly the case that machines are capable of performing non-routine cognitive tasks such as driving or legal writing. Frey and Osborne noted that advances in the field of ML facilitated the automation of cognitive tasks, the only exception to this threat was "Engineering Bottlenecks" ([17], p. 33), in other words, tasks related to perception and manipulation that, at present, cannot be substituted by machines since they cannot be defined in terms of codifiable rules and thus algorithms.

Subsequent research has also produced equally eye-catching, albeit slightly different, forecasts about the threat of job loss. One notable example is the report from the Brookings Institute – "What jobs are affected by AI?" The report argues the reason it has been difficult to "get a specific read" on AIs implications for work is because "the technologies have not yet been widely adopted" ([21], p. 3). Consequently, analyses from "Oxford (i.e. [17]), OECD, and McKinsey have had to rely either on case studies or subjective assessments by experts to determine which occupations might be susceptible to an AI takeover" ([21], p. 4). The report also points out that none of these analyses focused solely and specifically on AI, mainly concentrating on an "undifferentiated array" of automation technologies including robotics, software, and AI all at once. In contrast, the Brookings Report claims that it is drawing on a "new approach ... [based on]... quantifying the overlap between the text of AI patents and the text of job descriptions ... to identify the kinds of tasks and occupations likely to be affected by particular AI capabilities ([21], p. 4). The former provide a way to predict the commercial relevance of specific technological applications, for example, applicants willingness to pay nontrivial fees to file them is a proxy measure of patents likely uptake, and the latter because they provide a textured insight into economic activities at the scale of the whole economy. Using this method, the Brooking team undertook a granular, statistical analysis of the specific documented task content of occupations in a number of sectors, that are, potentially, exposed to emerging AI capabilities, for example, agriculture, finance etc., and drew the following conclusions: AI could affect work in virtually every occupational group and that better-paid, white collar occupation may be most exposed to AI, with business, technology and finance being particularly vulnerable (**Figure 3**).

2.3 Further perspectives on the 4IR

In parallel to the above developments, two sub-concepts have slipped into some media debates and discussions – Industry or Society 4.0 or 5.0. The former emerged from discussions between leading industrial and academic figures in Germany [22] and is a subset of the 4IR since Industrie 4.0 is predicated on the role of the IoT in facilitating the establishment of smart factories *guided by* sensors and other devices. This core assumption being that the above set of connections will alter the classic distinction between the production and consumption of material products, because it introduces the possibility of supply chains being managed by producers, suppliers and consumers to monitor and optimise assets and activities to a very granular level, in accordance with agreed societal values.

In contrast, the concept of Society/Industry 5.0 originated in Japan in 2016 in the Japanese Government's policy document the *Fifth Science and Technology Basic Plan* [23]. The defining difference between the two slightly different, but nonetheless related, societal and industrial conceptions, is that Society/Industry 5.0 is based much more comprehensively on the principle of *personalisation* than the 4IR. It affirms new forms of cooperation between man and machine and industry and higher education as human intelligence works with machine intelligence, to produce

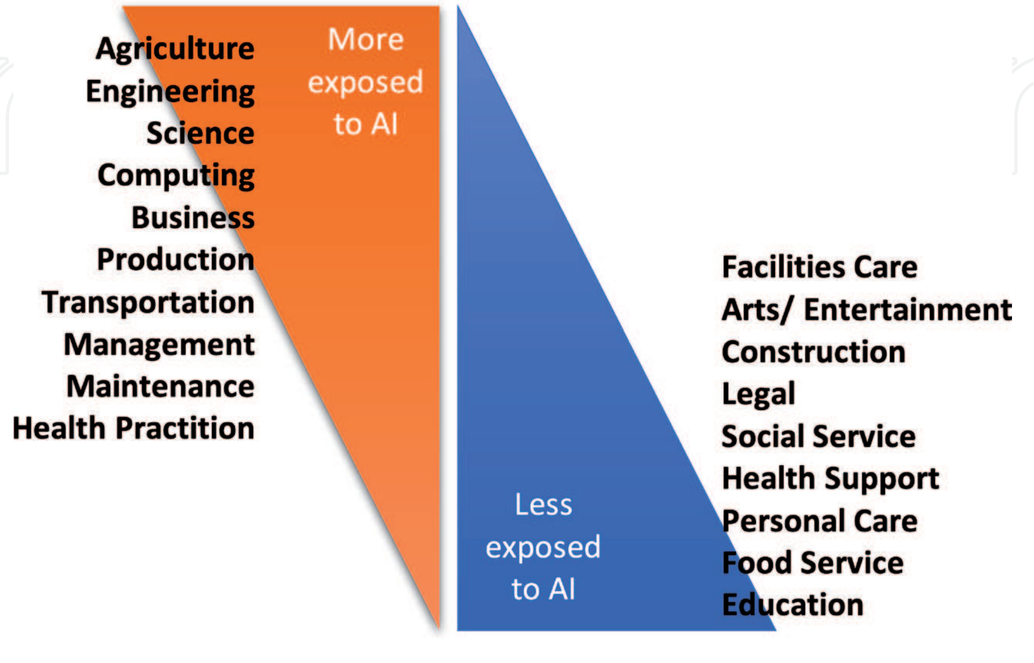

Figure 3.
Analysis of AI exposure scores in the US for major occupational groups. From Muro et al. [21].

products, services and systems that are genuine co-constructions between the state, market and civil society, and education and industry and communities [23]. This development elevates "knowledge exchange" between the private, public and third sector into a principle of co-construction rather a beneficial by-product of that way of working [24]. We return to this issue in the conclusion.

3. The 4IR and engineering

In parallel to the above developments engineering education has been in the grip of its own revolution for some time. Starting slowly in a small number of universities and pioneered by new schools of engineering such as Olin College [25] and The Lassonde School of Engineering "home of the Renaissance Engineer™" [26] there has been a growing debate on the skill set needed by the engineering graduate of the future. The core of these developments can be distilled to two main directions. The first is the inclusion of a boarder skill set into discipline-specific engineering degrees. Proponents argue that the 'math-science death march' [27] whereby multiple years of fundamental maths and science knowledge is required before students are able to engage in creative practical activities should be replaced with a more holistic approach to the formation of engineers with authentic, open and societally relevant projects from early in the curriculum [28]. The second, connected, direction is the need for engineers to have an interdisciplinary perspective. This follows from the first in that, if students are to be challenged with authentic, open and societally relevant projects, then these projects will no longer respect established disciplinary boundaries: they imply more integrate or interdisciplinary approaches. Therefore, the student teams assembled to address them must be interdisciplinary in nature unless the context is to be boiled down to 'toy' versions of the true problem [29]. Few, if any of the great challenges that we face as a society will be solved by a single discipline, while the emergence of new technologies created in a vacuum is already having a profound and often arguably negative impact on humanity.

The current work in reimagining skills for future industry strongly supports this direction of travel calling for interdisciplinarity to be at the heart of the design of future education systems. The report 'The skills implications of Industry 4.0' cites an industry example where the requirement is for "employees who are Industry 4.0 specialists with interdisciplinary skills for example uniting class mechatronics with good IT knowledge and strong social skills." ([2], p. 3). This example is supported by the outcome of the EU workshop on Enabling Technologies for Industry 5.0 where they identify a need in the workforce to be "Interdisciplinarity and transdisciplinarity, the requirement to integrate different research disciplines (e.g., life sciences, engineering, social sciences and humanities) is complex and must be understood in a systems approach." ([30], p. 6).

All the emerging models described above share a renewed focusing on creativity and interdisciplinarity within the engineering curriculum. While these are undoubted important skills for the modern role of the engineer and in the near future, will they be sufficient to prepare students for the future industrial landscape of digitisation, automation and eventually personalisation?

If we consider the future where "by 2025, humans and machines will split work-related tasks 50-50, while 97 million new jobs will emerge in AI, the Green economy and Care economy." [7] we see that there is both considerable need and significant opportunity for new skills. This dispels the views of some that I4.0 will replace existing jobs, as the Manpower report "Skills revolution reboot: The 3Rs - Renew, Reskill, Redeploy" [31] argues strongly, automation and hiring seem to go hand in hand. However, the Deloitte Global Millennial Survey 2020 [32], which concluded that 70% of young people believe they only have some of the skills that will be required to succeed in the work of the future raised significant concern about the perception of the current preparation.

However, we do note differences in the tone surrounding the key focus of industry 4.0/5.0. Although there is no universal definition. In the US and in China, for example in the 'Made in China 2025' governmental initiative [33] there is a heightened emphasis on the economic benefits of this revolution. Whereas in Europe, the European Commission provides a more human-centric voice with their definition, which states: "Industry 5.0 recognises the power of industry to achieve societal goals beyond jobs and growth to become a provider of prosperity, by making production respect the boundaries of our planet and placing the wellbeing of the industry worker at the centre of the production process." ([30], p. 6). In linking 'Industry 5.0' to 'Society 5.0' [34] they argue that a key focus of this revolution should be committed to achieving Sustainable Development Goals, including equality, climate change, peace, justice, eradicating poverty, and prosperity.

A message of global responsibility and societal good chimes with research in engineering education [35] as well as survey data, presented in the PricewaterhouseCoopers report, "Millennials at work – Reshaping the workplace", which suggests for millennials, once their basic needs such as adequate pay and working conditions, are met, the social values of the company become highly important when choosing an employer. The report states: "millennials want their work to have a purpose, to contribute something to the world and they want to be proud of their employer." [36].

In the UK there has been an emphasis on the process by which new graduates will obtain the skills of the future and how existing employees will be upskilled rather than focusing on the skills themselves. This is in line with the broader skills agenda of the UK Government and the longer-term industrial strategy which has necessarily had a change of perspective in light of BREXIT. The report "Manufacturing the future workforce" by the high-value manufacturing catapult calls for new models of education including the use of modular content related to emerging technologies to support the achievement of amended and new skills requirements ([37], p. 11). It also a follows a recognisable path of describing the need for co-creation between industry and academia in the development of such material ([37], p. 11). A similar recommendation is made by WorkSkillsUK in a report sponsored by the UK Department of Education - "greater co-operation between industry and educational institutions will be vital in ensuring the sector has the Industry 4.0 skills it needs for the future." ([2], p. 3) echoing the message of the European commission which suggests "increasing university-industry collaboration" and "Acknowledging the role of industry partners as educational, research and employment partners, and ensuring their engagement in the full student's learning experience," ([38], p. 17).

More recently there have been a number of reports that look to address the skills issue more directly. For example, a report for the European Commission in 2020 observed that "The main emphasis still needs to be put on the technical skills forming the core of this profession." ([38], p. 13) although then proceeds to offer a more cautionary tone, noting "However, rapidly advancing technology requires a general mind-set for continuous improvement and lifelong learning. It is no longer just about what one knows, but increasingly about one's ability to adapt to continuously changing circumstances and to constantly advance one's knowledge and skills. Focussing on technical skills only is thus not enough" ([38], p. 13), before supporting the agreement for the current direction of change saying "crucial non-technical skills … , among others, to critical thinking, creativity, communication skills and ability to work in teams." ([38], p. 14). This work is part of the EU's goal of "Europe Fit for the Digital Age" making digital innovation a priority within the member states. In achieving this it looks firmly toward skills: "Education, training, re-skilling and up-skilling are certainly among the most pressing issues to address when accommodating the digital transition in industries, as qualified human capital is of the utmost importance to make it a reality." ([38], p. 28).

Although the range of sectors considered is huge there is some agreement on the types of skills that the future workforce will require. One example of how they are could be broadly grouped comes from the World Manufacturing Forum's Top Ten Skills for the Future of Manufacturing [39]:

1. Digital Literacy
2. AL and Data Analytics
3. Creative problem solving
4. Entrepreneurial Mindset
5. Ability to work physically and psychologically safely and effectively with new technologies
6. Inter-cultural and -disciplinary inclusive and diversity-oriented mindset
7. Privacy and data/information mindfulness.
8. Handle increasing complexity
9. Communications skills
10. Open-mindedness toward constant change

This example is not atypical and demonstrates the mix of aspects that is usually seen in such work. It stimulates a debate as to the structures and processes best place to develop these skills [40]. However, most striking is the contrast between the typically formulation of current skill sets, heavily focused on knowledge of operations and the much more holistic requirements of the skills suggested of the future age. Although, not surprisingly, digital skills come top of the list, digital skills are not the only skills that will be pertinent for industry workers in the future. As can see, only four of the areas set out directly refer to digital skills: "digital literacy, AI and data analytics," "working with new technologies," "cybersecurity", and "data-mindfulness". The remaining 'skills' are more transversal skills linked to habits of the mind or ways of thinking. .

Although these lists provide an interesting starting point for the discussion of education of the future, the skills presented here are very much still framed in current terms. To be able to delve deeper into future needs, further interrogation is required of the role of the workforce in future industry to draw out more specific challenges to the education system of Industry 5.0.

4. Engineering and specialisation: current and future perspectives

Around the world, engineering in higher education responded positively during the latter decades of the 20th Century to support the move from standardised to customised and bespoke models of production in all spheres of industry. In the last 30 years for example, shifts have occurred in curricula and pedagogy, internationally as well as in the UK, and we have seen an increase in the models of engineering education that have moved from single-discipline siloes of engineering theory that prepared graduates for highly technical work in isolated domains, to increasingly practical educational compositions, focusing on engineering design. This development has, however, been uneven within departments of engineering in different countries. One common reason is that departments of engineering have continued to emphasise the value of foundational skills in mathematics and engineering sciences alongside the introduction of more practically-orientated approaches, and have selectively adopted appropriate curricula and pedagogic models.

From the discussion of future skills needs above, it is clear that this approach to education is going to be problematic. In the majority of universities, the disciplines do not just function as collectives based on thematic areas but are typically woven into the fundamental administrative structures of the organisation. Of course, organisation restructuring is not impossible, albeit considerably less common in the academy than in industry. However, the breaking down of such structures to enable evolutions in teaching approaches requires a multifaceted approach to leadership, that encompasses administration, research and teaching interest simultaneously. These systemic barriers to implementing, what is often seen in this context as radical change, are not to be underestimated. Although, despite many institutions still struggling to find the inertia to break free of these institutional bonds, we argue that such transformations are necessary if the truly integrated programmes required to deliver the skills requirements we identify are to be achieved.

4.1 Integrated approaches to engineering curricula

Despite, these challenges, there are many positive signs of developments that are excellent starting points to demonstrate the value of an integrated approach. For example, an increasing set of institutions have looked to frame their engineering curriculum in the profound societal needs of the 21st Century (e.g. Global Grand Challenges [41], 21st Century Grand Challenges [42], Grand Challenges for Engineering in the 21.st Century [43]), typically via the UN sustainable development goals to provide context to the technical education being provided. However, despite the progress in some quarters, there are continuing requests from industry for an improvement in graduates' communication and teamwork skills and to enhance their appreciation for, or experience with, the non-technical aspects of engineering solutions and innovation processes but, in addition, there is an emerging industry clamour for new technical competences and skills to match new technologies. Another challenge is that "Recently, a more comprehensive view of innovation has emerged which has led to educational interventions that aim at fostering creativity and thinking skills, as well as non-disciplinary skills such as entrepreneurial capacities, in a wide number of contexts, for all pupils and students, irrespective of their field of study" ([44], p. 206). There is a strong call for educators to instil qualities of resilience, creativity, empathy, flexibility and teamwork, as well as technical and analytical expertise, so as to enable students to be more innovative and entrepreneurial [45]. Given the pressing need for engineering competences, teaching that continues to be confined to single subjects (e.g. heat transfer in one course, thermodynamics in another, environmental engineering in another, technical writing in another, etc.) with little reference to one another, delays the development of proficiency in the fundamentals, methods of modern engineering practice, cultural literacy, and the generic competences required for success [46].

This drive toward greater interdisciplinarity is not new. As discussed earlier, this has been the direction many revisionist engineering educators have travelled from some time. However, we argue that as the 4IR takes hold, this will no longer be a beneficial approach to the formation of future engineers, but a necessary one. Current developments have been encouraged and supported by industry [47] and driven on by wide range of commentaries that have lamented the shortage of skilled graduate engineering that are available to enter the workforce [1, 48, 49]. The resulting innovations and developments have followed the principles outlined above, a focus on a broader skill set of creativity, team-work, and communications and an emphasis on interdisciplinary and authentic problem solving.

One of the first and most wide-ranging model came with the founding of Aalborg University in 1974 with an all-pervasive model of Problem- and Project-Based Learning [50]. The developments drew on the principles popularised by Barrows [51] of using problems as the central point around which the learning experience is based. In engineering, the problems typically are elicited as group projects, which occupy approximately half of the students' time. In the years since a number of notable new entrants have developed innovative models of engineering that balance the acquisition of knowledge and skills through problem or practice led curricula. In the late 90's the F.W. Olin Foundation founded the Franklin W. Olin College of Engineering in Needham, Massachusetts, USA with a vision of holistic approach to engineering education embracing creativity, innovation and entrepreneurship and design. A three-stage curriculum with design projects in each year is described, with a Multidisciplinary Foundation, followed by a specialisation phase and a realisation phase incorporating authentic capstone project experiences [25]. By taking this approach, the university has already attained several higher education goals in engineering education: their student body is gender balanced, they have the highest graduation rates in the US and graduates have successful pathways including graduate school attendance, employment and entrepreneurship. Olin especially expects to make a difference in terms of the supply of engineers into the US economy, and the world, and thus actively pursues collaborations with other higher education engineering institutes as well as industry, governments and other engineering stakeholders. Their ambitious goal is to revolutionise engineering education by treating students as engineers from day-one so they hit the ground running since the curriculum and pedagogy emphasise real-world scenarios with everything from project proposal to meeting minutes, to progress reports and plans on innovation iterations [52].

A decade later saw schools such as the Singapore University of Technology and Design (SUTD) and the Lassonde School of Engineering at York University in Canada admit their first students in 2012 and 2013 respectively. SUTD formed with a collaborated between MIT and Zhejiang University is a research-intensive university built on a multi-disciplinary foundation of no departments or schools. The curriculum is highly active and design-centred with a collaborative approach to maker-based learning in specialised 'fab labs' or make-spaces [52]. With a mission to create renaissance engineers, the Lassonde School of Engineering emphasised an entrepreneurial mind-set with a social conscience and a sense of global citizenship. It set out to have a 50:50 gender balance, something that would set it apart from the majority of engineering majors and through co-operative education and industry partnerships [26].

In recent years more have emerged. In 2016 Charles Sturt University in Australia established their new degree in Civil Systems engineering, with a heavy focus on entrepreneurial engineers in their local regional. The intense, fast-track programme offers a significant work-place learning complimented by a 'topic-tree' approach to learning that offers around 1000 topics arranged in branches that offer a flexible learning environment to the cohort. In the UK, two new entrants gained approval to accept their first cohort in 2021. TEDI London, part of a collaboration between Arizona State University, King's College London and UNSW Sydney offers an Industry-led and project-based curriculum in global design engineering. Conceived as an inherent interdisciplinary programme it arranges projects in themes (for example smart cities or user-centred design) rather than disciplines. NMITE, the New Model Institute for Technology and Engineering offers an accelerated degree in Integrated Engineering. Structured more like a job with 46 weeks of 9–5 Monday to Friday activity, it utilises real-world challenges in the form of 3 ½ week 'sprints' as part of a lecture-less and exam-less approach.

While some of the most innovative approaches have appeared in new entrants, that is not to say that significant innovation has not also occurred in traditional, incumbent universities. The nature of the reform is often different due to the need to navigate legacy structures and in most cases the reforms very much reflect the context of the institution. However, the scale at which these developments occur is often considerably larger that the that seen in the emerging schools.

One significant and globally supported response to reimagining engineering education is CDIO [53], a worldwide community of practice, that developed new pathways through an inspired set of principles that engineering education could use in strengthening its approaches to the thinking, becoming and doing of engineering. Educating through a process of Conceive, Design, Implement, Operate, CDIO describes engineers as professionals that contributed not only to a specific part of innovation, but holistically; solving problems identified by others. It identifies engineers as conceiving problems and areas of enhancement on their own and working with divergent groups of experts - being creative, as well as technical and theoretical - grasping that inventing is not enough if routes to implementation are not well understood or better, experienced, and that abstract models and complex logic had to result in something useful that could serve a purpose in the world. Becoming an engineer meant you could tap into many more facets of innovation that make use of hard-skills without limits as to the scope of activity. The importance of engineering processes is elevated to its current position: equal footing to the technical aspects of engineering. Yet implementing the new curriculum objectives, pedagogy and engineering education management would take on several forms and even meet resistance, contributing to the enduring imbalances in engineering education and offerings by HEI still apparent today.

Perhaps one of the best know reform programmes started in 2007 at the University of Illinois Urbana-Champaign. The Illinois Foundry for Innovation in Engineering Education or iFoundry, started offering cross-disciplinary curriculum options citing founding principles of the joy of engineering, learning, and community [27]. Today it is hardly visible as a programme in its own right, but instead has driven reform in engineering education across the school.

At UCL in London, UK, problem-based learning was first introduced in electronic and electrical engineering in 2004 in response to recommendations made by the Institution of Electrical Engineers (now IET) Industry Course Working Party. Over a number of years, it expanded and developed to integrate curriculum knowledge from various specific areas (e.g. electronics, communications, control, etc.) by emphasising learning that uses a problem/scenario as a starting point for learning, integrating knowledge, rather than compartmentalising and sequencing learning in individual silos. In 2014 UCL Engineering introduced a new programme that encompassed all engineering programmes in the faculty. The Integrated Engineering Programme (IEP) has an intake of around 1000 students and introduces problem-based and project-based learning to first-year engineering students across all departments, emphasising the success of this pedagogical approach. This familiarises students with self-directed learning at the start of their university studies, which will carry them through to lifelong learning in the workplace. It implemented Engineering Challenges, which give first-year students an opportunity to put their learning into practice through interdisciplinary, problem-based learning with a design focus in two major five-week design projects starting from the first day of term [54]. To support students, a strand of professional practice, including teamwork and communications skills, has been introduced. This builds through a pattern of interdisciplinary and disciplinary project-based activities culminating, at the end of the second year, in a two-week intensive programme, called How to Change the World, where interdisciplinary teams address 'wicked' problems within major global challenges such as sustainable energy or water provision [28].

Similarly, Purdue University, has adapted to the changing demands from engineering professionals by offering more than 25 different engineering programmes. For instance, a concentration in "Interdisciplinary Engineering Studies (IDES) and Multidisciplinary Engineering (MDE)" can encompass a specialisation in: acoustical engineering, engineering management, general engineering, international engineering studies, pre-professional (law, medicine, etc.) engineering, theatre engineering studies and visual design engineering. Open and tailored programmes such as these demarcate the new work engineers are preparing for, which is likewise highly specialised, comprehensive and holistic. The new structures encourage students to approach engineering as their vocation from the start of their studies; professionalisation into the field is therefore initiated from day-one.

Of the more recent developments, the inception of NEET or New Engineering Education Transformation at MIT is perhaps one of the most significant. Launched in 2017, this cross-departmental endeavour with a focus on integrative, project-centric learning, creates a series of 'threads' in the curriculum linking taught modules – some new but many existing – to projects framed around the new machines of the 21st Century. Advanced Materials Machines, Autonomous Machines, Digital Cities, Living Machines and renewable energy machines. This provides a model similar to that of the IEP at UCL where a curriculum transformation is brought about by augmenting elements of the traditional programmes through the introduction of cross cutting and interdisciplinary elements [55].

Although we are not widely seeing the impact of the 4th and 5th Industrial revolutions on universities, the potential implications are already reverberating across the majority of industry sectors. Discussions typically take the form of short-term opportunities, long terms challenges but almost always conclude with concern that a skills shortage will ultimately be a limiting factor in the pace of progress. It is clear that 4IR will impact in some way in all areas of life and business. Some, manufacturing for example, are naturally closest to the cutting edge of innovation where 3D and additive printing have been evolving for some time and in certain areas are already reaching maturity [37]. In service sectors, the availability of large datasets and rich potential of data mining are opening up vast new possibility. Although accusations of a wild west environment were lack of regulation and lack of understanding of the implications of these new technologies from law makers abound. Further into the future whole new sectors are being imagined that simply do not exist today. As a research field, quantum engineering blossomed in the last decade with prediction of its emergence as a mainstream technology in the next 10 to 20 years. This begs the questions; What will the Quantum Computing Engineering of 2035 look like? What skills and competencies will they need in this new role?

Many in each of these specialisms are already starting to address these questions. However, one common thread is emerging. The skills, knowledge and competencies no longer find neatly into the disciplinary boxes that we have used to categorise engineering for the past hundred years. These new engineering graduates will need to be interdisciplinary in ways we have not imagined in the past.

5. The concept of "fusion" skills

Research and discourse about the impact of the 4IR has, to a large extent as we saw earlier, focused on the aspect of substitution and automation: what tasks and activities smart machines currently are or soon will be able to perform and what the implications for the labour market are [17, 21, 56]. An alternative perspective has however been present by Daugherty and Wilson [5] in their book *Human + Machine: Reimagining Work in the Age of AI*. They argue that the above debate has been constructed around a separate focus on either tasks that are performed by humans or alternatively tasks performed by machines. As a consequence, an important range of activities is lost out of sight: hybrid activities where humans and machines closely collaborate – as exemplified in the case of robotic surgery. This is a radically different way of identifying not only the 4IR's or Society and Industry 5.0's skill needs compared with the production of lists of digital skills, but also the implication of these skill needs for engineering, as we explain below.

Employing a forecasting methodology, in common with the advocates of the substitution perspective, Daugherty and Wilson [5] nonetheless adopt a very different approach. Instead of asking the question – how might AI impact on jobs? – they ask – how might result in new jobs or new roles? To do so, Daugherty and Wilson [5] distinguish between three types of work activity: human-only activity, such as leading, empathising, creating and judging; machine-only activity, such as transacting, iterating, predicting and adapting; and human and machine hybrid activities. They sub-divide the latter into two categories: activities where humans complement machines, such as training, explaining, sustaining; and activities where AI gives humans "superpowers", such as amplifying, interacting and embodying. Based on this distinction about different types of human + machine hybrid activities, Daugherty and Wilson make the following inter-connected argument. Firstly, that: "the novel jobs that grow from the human-machine partnerships are happening in what they "call the missing middle – new ways of working that are largely missing from today's economic research and reporting of jobs." Secondly, the emerging human machine hybrid activities will require "fusion skills". Thirdly, the most important fusion skill will be to "reimagine" how AI can be used as a resource to transform working, living and learning. As conceived by Daugherty and Wilson [5], each of the skills they identify draws on a fusion of human and machine talents within a business process to create better outcomes. Their eight fusion skills are:

- *rehumanising time* – devoting more time to conductive creative research to address pressing problems.
- *responsible normalising* – the act of responsibly shaping the purpose and perception of human-machine interaction as it relates to individuals, businesses and societies.
- *judgement-integration* – the judgement-based ability to decide a course of action when a machine is uncertain what to do
- *intelligent interrogation* – knowing how best to ask questions of AI, across levels of abstraction to get the insights you and others need.

- *bot-based empowerment* – working well with AI agents to extend human capabilities and create superpowers in business processes and professional careers.
- *holistic (mental and physical) melding* – humans creating working mental models of how machines work and learn, and machines capturing user-performance data to update their interactions.
- *reciprocal apprenticing* – performing task alongside AI agents so people can learn new skills and on-the-job training for people so they can work well within AI-enhanced processes.
- *relentless reimagining* – the rigorous discipline of creating new processes and business models from scratch, rather than simply automating old processes.

These skills are, unlike the digital skill list we presented earlier that merely constituted a series of additions to extant interpersonal and technical skill such as, data analytics, based on forecasts about how humans will in future work with machines. Daugherty and Wilson formulated their fusion skills by analysing extant human-machine interaction and identifying human-only and machine-only skills, and then identifying on the basis of the future deployment or development of AI the new kinds of interactions that could occur between humans and machines in the context of work. This approach is therefore also radically different from Frey and Osborne [17] and Muro *et al*. [21] who operated with a classic social science binary assumption – automation or continuation – of work. Furthermore, unlike the advocates of the substitution perspective who steer clear of discussing the implications of their forecasts for organisational strategy, Daugherty and Wilson ([5], p. 3) argue that in order for companies to gain the most value from AI they will need to "reimagine" their operations and identify the requisite fusion skills.

6. Fusion skills and engineering degrees of the future

Working for Accenture – a global consultancy company – Daugherty and Wilson explore the reimagining of work processes through the introduction of fusion skills by presenting case studies of organisational change. We employ a slightly different strategy to reimagine engineering programmes. We draw on the scenario tradition, that is, combinations and permutations of the current state of affairs and anticipated social and technological change [3, 4]. Our scenarios are plausible, in the sense that they draw on current philosophy and design of engineering degrees, and they include significant developments – fusion skills – that exist in some small form in the present day and are anticipated to escalate in importance and significance over the next few years. The two scenarios we present both include features that are both possible and uncomfortable, for example, they highlight that although integrated/interdisciplinary degrees are positioned more favourably to engage with the challenge posed by fusion skills compared with single subject degrees, the development will have implications for the way in which members of those departments of engineering work with one another in future.

We present our scenarios to help departments of engineering identify different starting points for engaging with the challenge posed by fusion skills and to identify the way in which they might initiate discussions among academics about how to reduce those challenges, rather than to imply one scenario is inevitably better than the other.

We formulate our scenarios by drawing on the distinction Hoskin and Anderton Gough [57] made when looking at the development of interdisciplinary knowledge and skill in accountancy programmes. They distinguished between – "collection" and "integrated" approaches to programme and module design. The former refers to traditional discipline-specific programmes where the essential aim is to transmit blocks of knowledge in distinct specialist packages. In contrast, the latter promote and enable the integration of disciplinary knowledges, through breaking the old classifications and enabling learners to see knowledge in what we may call a more contextual way, through having a more integrated or interdisciplinary structure based around the use of projects, problems etc. These approaches are analytical distinctions, in other words, it is possible to characterise a degree in ideal typical terms as either consistent with the definition of collection, integrated or a combination of both approaches.

We use the distinction between collection or traditional single subject and integrated and interdisciplinary degrees to present our two scenarios of the engineering degree of the future. We do so to acknowledge that, despite the array of innovations in the design and delivery of engineering programmes, many departments of engineering remain firmly attached to the former type of degree. Our argument is that a homology exists between integrated/interdisciplinary degrees and fusion skills, which positions the former to embed fusions skills more comprehensively into programmes of study than would be the case with single subject degrees. Integrated/interdisciplinary degrees and fusion skills are both predicated on *contextualisation*: the former seeks to contextualise knowledge in relation to way in which an engineer, irrespective of their specialism may work with and relate to other engineers and their knowledge, once they are in the field of practice; the latter seeks to contextualise fusion skills in relation to future work practice. These are slightly different conceptions of contextualisation – curriculum contextualisation and work contextualisation. They are nonetheless complimentary because they are both concerned with relationships: relationships between engineers and relationships between humans and machines. It is this shared relational perspective that provides the basis for identifying how to embed fusion skills into integrated/interdisciplinary engineering degrees. In contrast, single subject degrees are far less contextual. They tend to prioritise offering engineering students depth of knowledge in their chosen specialism, rather than opportunities to explore the contextual basis of both the specialist knowledge being studied and its future relationship to engineering work practice. One way such degrees do sometimes mitigate the concern for depth is by offering students work placements.

We can see, at a glance, the significant difference between the way in which fusion skills could become part of single subject and integrated/interdisciplinary degrees in **Table 1**. below. The starting question is similar for both types of degree – to follow Daugherty and Wilson and identify ways in which AI might enable staff & students to secure an improved work-life balance by rehumanising time. We see swiftly, however, significant divergence when we consider the way in which the different degrees are positioned to respond to the challenge of agreeing philosophy, pedagogy & assessment to incorporate AI into their extant designs. The difference is encapsulated in the terms – embed or include.

If we take one of the fusions skills, 'judgement-integration', we can see that to fully appreciate the complexity of the judgements that will be necessary in the design of, for example, autonomous vehicles, we see that the range of expertise necessary extended well beyond any single discipline. Fleetwood [58] frames the issues related to ethics judgements in the design of autonomous systems in term of public health and captures the range of competing considerations that are required of students. While we would never suggest that any single engineering student could

Traditional single subject degree	Fusion skills	Degree with integrated/interdisciplinary elements
Identifying ways in which AI might enable staff & students to secure an improved work-life balance	*rehumanising time*	Identifying ways in which AI might enable staff & students to secure an improved work-life balance
Agreeing philosophy, pedagogy & assessment to add AI into modules	*responsible normalising*	Agreeing philosophy, pedagogy & assessment to incorporate AI into project & problem-based activity
Include examples of machine 'failure' or 'worrying' results in modules	*judgement-integration*	Embed examples of machine 'failure' or 'worrying' results & opportunities into project & problem-based activity to provide students with opportunities to decide appropriate response
Include examples of how experts have asked questions of AI, across increasing levels of abstraction, in modules	*intelligent interrogation*	Embed opportunities into project & problem-based activity for students to learn how to ask questions of AI, across increasing levels of abstraction throughout their degree
Include opportunities in some modules for students to work with AI to extend their capabilities	*bot-based empowerment*	Embed opportunities into project & problem-based activity for students to work with AI to develop AI-capacity & understand how AI solutions cut across engineering specialisms
Include examples of how AI works and learns to capture user-performance data to update their interactions	*holistic melding*	Embed opportunities into project & problem-based activity for students to create mental models of how AI works and learns and also to work with examples of how AI has captured user-performance data to update its interactions, to understand the difference AI learning has made for the field of engineering
Include case studies of how engineers are working alongside AI so students understand the skills they will need to develop when working in engineering research or professional contexts	*reciprocal apprenticing*	Embed opportunities into project & problem-based activity for students to perform task alongside AI agents so they can learn new skills and begin to work within AI-enhanced processes
Include case studies of how new processes being developed from scratch in engineering research or professional contexts	*relentless reimagining*	Embed opportunities into project & problem-based activity for students to gain experience of new processes being developed from scratch
Discipline-specific understanding, with practical awareness	**Outcome**	Holistic conceptual understanding & practical experience

Table 1.
Engineering degrees of the future: 2 fusion skill scenarios.

reasonably be expected to be expert on all of the areas necessary, from the AI to the sociology, psychology and fundamentals of human-computer interaction, it is undoubtably the case the opportunities to engage students in a nuanced and diverse exploration of the issues at hand is limited in a single discipline. In an integrated curriculum model, these no longer become the preserve of the just computer scientist. This argument apes some of the original discussions that led to the integrated forms of degrees that we see today. If we take the design thinking framing of Brown [59] and IDEO we see engineering design and decision making consisting of potentially competing evaluations of feasibility, desirability and viability. Inherent this calls for a broad palette of skills and deemphasises the validity of single disciplinary view-point in decision making. If we continue to compare and contrast activities typical of a single subject degree with those possible in an integrated and interdisciplinary context, we see further evidence of the support these broader contextual framings provide for fusion skills.

There are, however, some areas where the contrast is not so stark which highlights a second key aspect that we argue is necessary in future skills development but that might also be viewed under the heading of integration. That is Industry-Academia integration. For many, a linear model of professional formation still pervades, a degree in the academy followed by profession experience in the workplace. Although, placements and year in industry programmes are not uncommon, reductions in student funding, and competition for industry support, for examples in the UK from apprenticeships and T-Level qualifications, show that while not necessarily at risk, this model is unlikely to expand significantly as currently formulated. Additional, while undoubted positive for the student, it is hard to argue that the majority are truly integrated – where training and experience in the workplace and education in the academy combine to make a learning experience that is greater than the sum of its parts. There are successful examples. Some of the best degree apprenticeships achieve this, as do models such as Charles Sturt discussed above. However, we would argue that a complete reimagining of industry-academia interaction in the formation of professional engineers is required to address the necessity of fusion skills in the future workforce.

Whilst we have shown that an integrated degree offers the best opportunity to elicit the environment for students to explore fusion skills within a university programme, the level of authenticity possible is always constrained by the bounds of the academic environment. The later skills discussed in **Table 1**, ideally call for authenticity that may best be provided by industry partners. *Relentless Reimagining* calls for 'creating new processes and business models from scratch' and while this can be developed at a distance from industry, it is undoubted challenging to replicate the full and nuanced range of competing design requirements that interplay in the conception of a successful business process. The danger is that without access to the realities of the workplace, even the projects delivered with an integrated degree regress to the 'toy' problems that drove educators away from single discipline projects in the first place.

A model where workplace learning integrated into the engineering curriculum and the formation of a professional engineering is necessary development. Two considerations will have to be borne in mind: the role of AI and the insights that can be accrued from short placements/internships. In the case of the former, it will be important to commission research on models of reciprocal apprenticeship in university research teams and companies who are either introducing or developing fusion skills in their teams, to identify their new hybrid learning processes. In the case of work placements/internships it will be important to identify best learning practices. Both sources of intelligence can then be used to ensure workplace learning is connected to both university- and company-based learning, with explicit interrelationships drawn. This is likely to be especially relevant in the short-term for companies as they reimagining their development processes and formulate new procedures for user-engagement and product/process design, and for departments of engineering as they consider the implications of our two scenarios.

7. The post-Covid challenge for universities and departments of engineering

Having identified the type of challenges associated with the embedding of fusion skills into engineering degrees, we now locate that challenge in the post-Covid context. We paved the way for this discussion earlier when we referred to Schwab's argument that responding to Covid will involve a *great reset*: governments working together to orientate the market toward fairer outcomes, targeting investments, especially in AI, to advance shared goals, such as equality and sustainability, and harnessing the innovations of the Fourth Industrial Revolution to support the public good, especially by addressing health and social challenges. Clearly, the fusion -kill reimagining of engineering and engineering education outlined above is central to all of these reset goals. To demonstrate why and how, we conclude by drawing on Crawley and colleagues' [55] argument that universities perform best as engines of economic and social development when they systematically exchange knowledge with their partners in industry and government.

For too long, this "exchange" has operated, according to Crawley and colleagues [55] like a one-way street, with universities sending graduates and research out into the world without considering how they can best contribute to the goals of accelerated innovation, economic growth, and now recovery in the face of the challenges of the Covid-19 pandemic. To combat this tendency Crawley and colleagues put forward some practical suggestions to assist universities to reimagine in their educational and research activities as well as catalysing innovation to strengthen knowledge exchange — the flow of people, ideas, and technologies — between universities and their partners in a way that is more aligned with the great reset.

Our argument above about the fusion skills clearly presupposes knowledge exchange between universities and employers, with explicit intention of improving the social outcomes of engineering. We propose therefore that the development of fusion skills requires a reimagining of *the design and delivery of engineering degrees*. And, we have identified two scenarios to assist universities to address this challenge.

In advancing this argument, we also recognise with Crawley and colleagues that, research needs to be reimagined. The development and implementation of fusion skills will require collaborative research within and across scientific disciplines — or even rejecting the idea of a discipline as an organising principle for university research – and assemble teams of 21st-century thinker and doers" to conduct research that is problem-oriented, and not disciplinary, and involving industrial partners and collaborators since they are, as we have indicated above, essential to the development and implementation of fusion skills. This suggestion, in turn, implies *reimaging of the field of engineering education so that it acquires a reputation for reporting these developments to academic and industrial audiences.*

The engineering degrees and research of the future also calls for a catalysing of innovation, in other words, universities moving beyond research to create technologies, business models, health-care systems, and other products.

We recognise that responding to this agenda requires changes to universities' faculty development, facilities, governance, and outreach to external partners, and that there may well be some tension about departments of engineering discarding some of their, and universities, historic roles and values. In accordance with the spirit of the great reset, we suggest this debate should be held and given serious attention.

8. Conclusion

The core argument running through this chapter about the implications of Society 5.0/Industry 5.0 for engineering education is that they presuppose new, rather than, additional skills which we have defined as *fusion* skills. We have, however, given an additional twist to the source of inspiration for our chapter and this edited collection by locating our argument in relation to the challenges associated with the great reset. We have therefore argued that what initially might have appeared to be only an issue of *technique* [60] is also an issue of *vision* about the type of society and life that imaginative, talented and environmentally responsible departments of engineering and the engineers of the future they produce can help to bring to fruition.

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