FUSION SKILLS FOR ENGINEERS WORKING IN INDUSTRY 5.0

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Abstract: The introduction of the digital technologies that are heralding the coming of industry 5.0 present unique challenges to engineering education and engineering educators. The knowledge and skills requirements that have been fundamental to engineering education and imparted to engineering graduates across recent generations are likely to be, at best supplemented, at worst usurped by emerging digital skills in application specific data science, machine learning and AI. While some trends are emerging in the nature of these skills what impact they will have and how engineering education will need to react is less clear.

In this paper, will we review several conceptualisations of these skills and aim to draw out the important aspects that engineering educators should be considering when designing future looking curricula. One particularly persuasive framing is that of fusion skills. These skills move on from the typically viewpoint of jobs being catagorised as either human activities or machine activities and looks towards activities where humans and machine work in concert - as hybrid activities - requiring a fundamentally different skill set. We conclude by describe what an engineering curriculum might look like that integrates and promotes such emerging fusion skills to ensure our graduates are prepared to work in industry 5.0.

Society 5.0 and Engineering

The concepts of Industry/Society 5.0 have recently slipped into some media debates and discussions – Industry or Society 5.0. These concepts originated in Japan in 2016 in the Japanese Government's policy document the Fifth Science and Technology Basic Plan (Salgues, 2018). The defining feature of Society/Industry 5.0 is that they are based on the principle of the deployment of digital resources to personalise products and services. In doing so, the concepts affirm new forms of cooperation between man and machine and industry and higher education as human intelligence works with machine intelligence, to produce products, services and systems that are genuine co-constructions between the state, market and civil society, and education and industry and communities (Salgues, 2018). This development elevates "knowledge exchange" between the private, public and third sector into a principle of co-construction rather than a beneficial by-product of that way of working (Crawley et al. 2020).

At the same time engineering education has been engaged in a debate about its future direction. While some have engaged revolution, most pioneered in new schools of engineering such as Olin College (Kerns, Miller and Kerns 2005) and The Lassonde School of Engineering "home of the Renaissance Engineer™" (Zhuang and Newland 2017), some seen the process as more evolution (Mitchell 2021). However, for both there is a similar direction of travel, focused on the skill set needed by the engineering graduate of the future in two main areas. The first is the inclusion of a boarder skill set into discipline-specific engineering degrees. Proponents argue that the 'math-science death march' (Goldberg and Somerville 2014) 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

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of engineers with authentic, open and societally relevant projects from early in the curriculum (Mitchell et al. 2019). The second is the need for engineers that have an interdisciplinary perspective and the skills to engage with a wide range of disciplines and professions as well as society. 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 (Roach, Tilley, Mitchell 2018). 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 (Workskills 2019; Müller 2020, p6).

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?

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." (European Commission 2020 p13) 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" (European Commission 2020, p13), 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." (European Commission 2020, p14). 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." (European Commission 2021, p28)

Given the huge range of sectors considered it is difficult to draw out a definitive set, however there is some agreement on the types of skills that the future workforce will require. One insightful grouped comes from the World Manufacturing Forum's (2019) Top Ten Skills for the Future of Manufacturing:

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 towards constant change

This example is not atypical and demonstrates the mix of aspects that is usually seen in such work. 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.

It is clear that Industry 5.0 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 (Collier and Shakspeare 2020). 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.

“Fusion” Skills

Research and discourse about the impact of AI has to a large extent 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 (Frey and Osborne, 2013; Munro et al. 2019; Nedelkoska and Quintini, 2018). An alternative perspective has however been present by Daugherty and Wilson (2018) 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. This is a radically different way of identifying 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 (2018) – how might AI result in new jobs or new roles? To do so, Daugherty and Wilson (2018) 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.”

- the emerging human machine hybrid activities will require “fusion skills”.

- 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, 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 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.

Fusion skills and Engineering Degrees of the Future

Daugherty and Wilson explore the reimagining of work processes through the introduction of fusion skills by presenting case studies of organizational 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 (Ringland and Schwartz, 1998; Schoemaker, 1995). We supplement that tradition with the distinction Hoskin and Anderton Gough (2004) 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. 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 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. Figure 1. below demonstrates the significant difference between the way in which fusion skills could become part of single subject and integrated/interdisciplinary degrees. 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. However, significant divergence occurs 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.

Figure 1. Engineering Degrees of the Future: 2 Fusion Skill Scenarios

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,	*intelligent interrogation*	Embed opportunities into project & problem-based activity for students to learn how to ask questions of AI,

across increasing levels of abstraction, in modules		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

Considering 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, the range of expertise necessary must extended well beyond any single discipline. Fleetwood (2016) 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 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.

The inevitable conclusion we draw from this consideration of the skills development required of future graduates is that an integrated degree offers the best opportunity to elicit the environment for students to explore fusion skills. However, we must also acknowledge that within a university programme the level of authenticity possible is always constrained by the bounds of the academic environment. Many of the skills discussed in Figure 1, 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 is integrated into the engineering curriculum and the formation of a professional engineering is a 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 are re-imagining 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. It should be notes that our focus in this paper has been future engineers for the engineering sector rather than those remaining in the higher education (HE) sector. We nonetheless recognise that our argument has implications for HE and that warrants further consideration.

Conclusion

In this paper we propose that the skills that graduates will need in the coming decades are a radical departure from the professional formation of an engineer that has been the norm throughout the 20th Century. We highlight that while they are difficult to predict for a specific section, there are common themes that are emerging and that the conceptualisation of 'fusion skills' is a useful starting point to consider the skill that graduates will need and what reimagining of the engineering education process is necessary to support their development. These skills pertain to roles where human roles are supplemented by machine or where human intervention mediates machine driven activities. We argue that the progress towards integrated/interdisciplinary degrees that is already in train in some engineering schools is highly beneficial and that such programmes are therefore positioned more favourably to engage with the challenge posed by fusion skills compared with single subject degrees. However, we also argue that greater emphasis on a true integration of workplace practice through collaboration with industry is also required if the full breadth and depth of these skills is to be realised.

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