Royal Academy of Engineering

Engineers 2030: redefining the engineer of the 21st century

Future skills needs – a review of the literature

Contents

1 INTRODUCTION

This literature review seeks to critically analyse and synthesise existing recommendations on future engineering skills to provide evidence and inform the National Engineering Policy Centre's Engineers 2030 project.

Engineers 2030 is the engineering profession's multiyear flagship policy project that will enable transformative, positive change to engineering education and skills systems. It aims to:

- **determine the foundational knowledge, skills, and behaviours needed by engineers and technicians to create a 21st century world in which both people and the planet can thrive**
- **understand the systems, cultures, and policies currently in place in the UK to deliver this**
- **define the principles for how education and skills systems need to change to be effective in developing the engineering knowledge, skills, and behaviours needed to meet global challenges.**

The project consists of two phases. During the first phase (July 2023–March 2024) the Royal Academy of Engineering will work in partnership with over 40 engineering professional bodies in the National Engineering Policy Centre. They will engage with wider stakeholders to develop and agree a case for change. The second phase, (April 2024–March 2025) looks more deeply into parts of the skills ecosystems where change can be most effective in the short/medium term. The programme will set the evidence and rationale for change with recommendations for governments, employers, educators, and the engineering profession.

As an important step towards determining the foundational knowledge, skills, and behaviours needed by engineers and technicians to meet 21st century global challenges, this literature review critically analyses and synthesises existing recommendations on future engineering skills. The key rationale for carrying out such a review can be outlined as follows:

The answers we seek most likely already exist: Even a quick review of the many and various future skills initiatives conducted in recent years shows how much work is already being done in identifying future skills needs relevant to engineering. While no definitive skills framework exists as a useful basis for Engineers 2030 the answers we seek should, to a large degree, already exist across the existing grey literature. This review aims to enable the project to build upon work that has already been done.

Gaps in the literature will be identified and filled through further research and engagement with the professional engineering community and wider stakeholders.

These answers exist in a distributed and uncoordinated way: The engineering sector has produced many high-quality skills policy outputs and demonstrated some commonality, but the work has been carried out either independently or through discrete projects. These outputs either do not align, or even acknowledge that other work is taking place, or they simply duplicate it.

Clarity would be helpful about specific 'skills statements': Many (not all) of the existing reports provide general and high-level accounts of skills needs but stop short of articulating precise 'skills statements' (that is, statements that can be clearly written in the form: "An engineer in 2030 will be able to …"). Although we can identify some topics where further detailed work is required (such as data skills), without conducting a literature review it is difficult to prioritise aligned, commissioned work.

The Royal Academy of Engineering's Education and Skills Policy team followed a structured methodology to arrive at a clear, concise account of the skills needs of future engineers. This methodology is outlined in full in Appendix A.

1.1 Focal questions

This review aims to answer the following questions:

- What consensus exists on which social and economic needs our future engineers must respond to?
- What principles underpin the new knowledge and skills needs of future engineers relative to these needs?
- Are there any implicit contradictions/challenges contained across the commonly agreed needs/principles.
- What are the priority questions for further commissioned research.

This literature review will not answer the following questions:

- What knowledge/skills are provided by the current skills ecosystems that are no longer needed?
- What specific new knowledge/skills will future engineers need in key priority areas.

2 KEY FINDINGS FROM THE LITERATURE REVIEW

The two major changes impacting the activity of future engineers are digitalisation and data, and sustainability. These themes are dominant through most of the literature reviewed in this study. There is a prominent engineering 'skills-nexus' opening around digital-data-electrification-green skills, with an associated skills gap that is well documented. However, it is rare to find literature that outlines these needs in terms of specific 'can-do' statements that clearly outline what an engineer needs to do in response to the unfolding changes.

The UK is facing an acute digital skills crisis. Digital and data skills are foundational, intersectional, and an increasingly pervasive requirement – especially for emerging technologies. But supply of these skills is failing to keep up with demand and this poses significant risks for growth and productivity. This challenge is particularly acute in some professions, for example data security, but the consistency of this message across literature covering a wide range of sectors is particularly worrying. It suggests that the digital skills gap will continue to widen as the needs of different sectors impact upon and compound each other.

Future engineers will be required to be globally responsible. Engineers are being increasingly required to work at the forefront of areas of social and environmental challenge, and this is impacting the way they need to work. This ranges from the need for engineers to have a better knowledge of their specific operating and regulatory contexts (including the wider environmental and social impact of their work), to more wide-ranging issues such as those underlying current diversity challenges, which are key to bringing sorely needed skills into engineering. Ethics and other humanities-based skills will therefore increasingly be an important part of engineering design and delivery.

Categorising emerging knowledge, skills, and behaviours is difficult. The key challenge faced in attempting to understand such a broad-ranging subject as future engineering knowledge, skills, and behaviours, is how to make sense of, and structure the vast amount of information that is available. A common approach is to first define a major transformation, categorise the processes and technologies linked with that transformation, and then think about the associated knowledge and skills. There are some examples of this approach being carried out instructively as part of a well-developed methodology (such as the High Value Manufacturing Catapult's Skills Value Chain methodology[1]). But it often results in unwieldy levels of complexity, with reports that either get lost in the detail, or sacrifice lucidity to broad, overlapping, and sometimes vague classifications such as 'green skills'. The problem is that knowledge, skills, and behaviours are as complicated, interconnected, and messy as the societies that possess them.

The way skills needs are communicated is often confused or incoherent. There is an evident lack of coordination and consensus on how to define and differentiate emerging skills needs, and this is underpinned by the lack of a common shared language. This is not to suggest that there is an issue with the quality of the work that has been undertaken, rather it may be a product of the way skills-focused activity is structured and siloed through our institutions. The review also encountered accounts of a mismatch in perspectives on skills proficiency levels between graduates and employers which might also be symptomatic of this broader lack of clarity.

When thinking about knowledge, skills, and behaviours, it is useful to start from a consideration of the context of their application. During the analysis of the data, we collected as part of this review, we considered several different ways of structuring the information to make sense of it. We eventually hit upon the idea of reversing the common approach outlined above. Rather than establishing a technology-based theoretical framework to fit the qualities of practising engineers against, we started with the lived experience of practising engineers as a foundation upon which to develop a practically orientated framework. Most engineers are employed in a business context and apply their knowledge, skills, and behaviours in productive ways within a given operating environment. We used this idea to structure our findings. The first half of the study looks at the qualities of practising engineers that are essential to productivity and growth, and the second half looks at how engineers must navigate a changing operating environment. This structure has its own limitations, but we consider this approach to be an effective way of talking about future skills needs in a way that spans sectors, disciplines, and technology areas.

Radical changes are needed to the way we think about skills. As technological change increases in pace and complexity, it requires engineers to think differently about how their skills relate to their profession. The pace of change across many of the skills areas we have looked at is significant, and mutually compounding. Adaptability, flexibility, the development of multidisciplinary skills, and the ability to rapidly upskill or reskill therefore emerge as clear priorities. Related to this is the increasing importance of 'meta-skills' – being able to understand your skillsets, self-assess your education and training requirements, and plan to upskill in strategic and effective ways.

Radical changes are needed to the way we think about the deployment of skills. Skills distribution and deployment was a significant theme to emerge from this study. This includes questions of how skills demand and supply are distributed around the UK, and, importantly, how engineering skills are required to transition into a sustainable, equitable, and thriving society. For example, mobility challenges will require not only remote working technologies, but a rethink about how to efficiently use space and resources. Central to these issues is the correct governance and management of other people's skills in the workforce. This includes nurturing the interdisciplinary skills needed to understand how to capitalise on, and strategically engage with new technologies.

A recognisable core of traditional engineering skills will remain important. Emerging challenges and technologies have gained a lot of attention within the literature reviewed. But it is also clear that traditional engineering knowledge and skills associated with technical challenges will remain important. Traditional engineering skills including problem solving, innovation, creativity, the application of fundamental concepts, and subject specialisms will remain core engineering knowledge and skills requirements. But the application and development of these qualities will need to be enhanced by a more critical approach – including elements of 'problem finding' or systems thinking, for example.

The engineering profession must better define and promote systems thinking as an essential component of engineering practice. Initial feedback received on the content of this review questioned whether sufficient weight had been placed on systems thinking. Systems thinking is being increasingly recognised as an important component of 21st century engineering practice, especially within academia. However, the way we have presented systems thinking in this review reflects how the concept is treated in the literature we reviewed – acknowledged as an important requirement across different sectors and challenges, but nowhere receiving the dedicated attention it requires.

Soft skills will remain important for engineers. Although care must be taken with how they are defined, soft skills will remain important for achieving engineering solutions within business or broader societal contexts. For example, research and development (R&D) and innovation skills are essential to businesses growth, but there is a wide skills divide between academic and entrepreneurship/commercial skills that is having a significant impact on UK economic performance and productivity. Teamworking, project management, and communication are all important skills that enable practising engineers to successfully navigate their business-centred operating environments.

Understanding how technology and people interact with each other is essential for predicting future skills needs. As technologies develop and merge in unexpected ways it is necessary to consider how technological considerations merge with nontechnological ones. This applies to how technologies interact with, and indeed change, society. However, it is also important to consider how human skills are applied alongside new technologies. A prominent example of this has been seen with the emergence of artificial intelligence (AI). Despite the clear advantages this, and other 'black-box' technologies can bring, there are many challenges that engineers face in particular, such as the ability to engage information critically (both in terms of the evidence they draw upon for their work, and in how they communicate with team members, customers, and the wider public). It is important, for example, that engineers understand the reality of an emerging technology from the hype surrounding it and can communicate and discuss this reality with external audiences. Engineers must serve as a trusted experts both within the supply chain, and increasingly with the general public. This increases the relevance of cultural skills, and especially language skills.

3 DEFINING ENGINEERING SKILLS

One of the key observations from this study is that there is an overall lack of consensus regarding how to define and differentiate the 'knowledge, skills, and behaviours' of engineers.

One of the key techniques applied in the literature on engineering skills has been to cluster skills into the skillsets required for particular jobs or job types. This approach is a popular one, because it then allows studies to be reinforced with the large amount of data drawn from job advertisements. However, these clusters have been developed individually by different sectors, use different methodologies for categorising them, are discussed using different language, and can result in clusters that overlap with each other[2]. These challenges are associated with broader difficulties in defining an engineer that have already been noted[3].

In this study we have, where possible, aligned language used to describe different skills with the O*NET taxonomy (an American database of occupational requirements and worker attributes)[2], which is a widely used taxonomy and has been most rigorously developed. To define engineering, Sir Robert Malpas FREng's widely accepted definition still stands the test of time[4]:

Engineering: the knowledge required and the process applied, to conceive, design, make, build, operate, sustain, recycle, or retire something with significant technical content for a specified purpose: a concept, a model, a product, a device, a process, a system, a service, a technology.

Knowledge: 'know-what'. The growing body of factual information, such as calculus, mechanics and thermodynamics, and design processes that is required for engineers to intellectually understand how to fulfil their role.

Skills: 'know-how'. The practical application of knowledge and the manifestation of the engineering habits of mind. This both refers to 'technical' skills (for example, data management) and 'soft' skills – transferrable skills to enhance behaviours (for example, communication, time management, creativity).

Behaviours: 'Engineering Habits of Mind'. The fundamental characteristics of an engineer and how they act. These include systems thinking, adapting, problem finding, creative problem solving, visualising, and improving[5].

Technology: An enabling package of knowledge, devices, systems, processes, and other technologies, created for a specific purpose. The word technology is used colloquially to describe either a complete system, a capability, or a specific device.

Innovation: The successful introduction of something new. In the context of the economy, it relates to something of practical use that has significant technical content and achieves commercial success. In the context of society, it relates to improvements in the quality of life. Innovation may be wholly new, such as the first cellular telephone, or a significantly better version of something that already exists.

Further categories, such as 'green skills' have been defined where they are first used.

Categorising skills across engineering will remain a challenge. Different kinds of skills work in different ways, interact with each other to varying degrees and morph between contexts. Despite the care we have taken to be clear with our categorisation, we are aware that our approach will not find universal agreement and we will remain keen to hear from engineering stakeholders with alternative suggestions.


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> Digital skills are widely accepted as foundational to all future engineering careers and fundamental to how all other skills are now acquired and put into practice

4 SKILLS FOR GROWTH

4.1 Digital and data

4.1.1 The foundational nature of digital and data skills

Digitalisation is the most prominently cited transformation impacting engineering skills requirements across a staggering range of applications, from computer aided design and manufacturing, to programming, big data, and machine learning[6,7,8]. Digital skills are widely accepted as foundational to all future engineering careers[9,10,11,12] and fundamental to how all other skills are now acquired and put into practice.

Such skills range from essential digital skills needed to use a computer, work remotely, and manage digital information[13,14,15,16], to highly advanced skills associated with big data and AI, robotics, advanced electronics, and cyber security[10,15,17,18,19,20,21] and cover just about every aspect of modern engineering.

As a fundamental set of skills, they are closely interconnected with the other key transformations impacting engineering skills requirements (net zero and global sustainability), usually referred to as 'green skills'. Many prominent technologies driving progress towards net zero are electrical systems, controlled digitally, so without digital skills the transition to net zero is impossible[9,22,23]. This will be covered in more detail in Sections 5.1.3 to 5.1.5.

4.1.2 The increasing prevalence of data

The importance of data skills for engineers in most engineering sectors has become apparent with the digitalisation of industry. This has accelerated in the last few years in the context of the green transition, the emergence of big data and machine learning, and the increasing pace of technological change. An engineer who can navigate the use of data is in great demand[47] and many sectors are reporting an acute data skills gap, even at a foundational level[24,25,26,27,38]. Data gathering, numeracy, statistics, literacy, handling, and interpretation skills are now expected, rather than discretionary, for engineers[18,25,26] and there is an increasing demand for the specialist skills associated with data science, analytics, data systems, and governance[28]. This trend is predicted to increase through the next decade and into the future as new technologies such as advanced robotics, AI, remote operations, and advanced data handling[25,28] mature.

With the ubiquity of data across every facet of public and professional life, the skills needed to secure and protect data, and to determine the quality of external data has never been more important. Engineers must now master the skills required to review and protect data as standard from the start of their education. They also need to demonstrate a more general proficiency with data ethics and regulation[18,26,28,29].

4.1.3 The digital and data skills gap

An unevenness between the supply and demand for digital skills has created issues for many industries in their drive towards digitalisation and realising the new possibilities it can unlock[10,19,30,31]. This is in turn impacting the productivity and resilience of the UK economy[10,19] and has required businesses to invest significant sums into their digitalisation programmes to cover higher costs associated with the digital skills gap[15].

This skills gap, and the likelihood it will worsen over the next five to ten years, has been the focus of a significant amount of the literature reviewed for this study. Industries across a range of sectors are struggling to fill vacancies, with basic digital skills gaps harder to solve than advanced ones, and problems especially acute at the technician level[10,13,14,16,21,30,32,33]. In addition to this, over half of global manufacturers surveyed by the Learning and Work Institute predict an increased demand for both basic and advanced digital skills over the next five years[34]. While there are some signs that this might be changing as a result of a new generation of young people that have grown up in a digital world[35], the continued lag of higher education and rapid pace of change in the digital sector suggests that digital upskilling will remain an essential component of an engineers' working experience[12,36].

There are striking differences between literature covering the views of industry and students on their data skillsets. While students and some industry representatives suggested that younger generations exhibit innate data skillsets as a result of them growing up in a more data-rich environment[25], many in industry felt that students left university with only basic data skills. The practical applications of those skills in the context of advancing data technologies has meant that there is an over confidence among students who then struggle to meet the demands of industry[25]. This lack of alignment may, in part, be related to the lack of a clear framework of specific, practically orientated skills statements highlighted in Section 4.1.4. It is difficult for students and employers to find a common understanding of data skills requirements because they have not been clearly defined.

4.1.4 Intersecting nature of digital and data skills

The need for digital skills, such as coding and data handling, is widely recognised throughout industry[37]. However, the usefulness of these skills requires a foundation of wider skills and behaviours that may be less immediately obvious when discussing digital skills. Examples include governance, active listening, conflict resolution, self-leadership, persistence, understanding the impact of technology on a business, and being able to instigate changes to production and working practices[14,38,39]. The wide range of associated skills needs is a result of the way digital technologies intersect with most areas of work.

A striking observation concerning the literature on digital skills was the comparative lack, compared to more established engineering practice, of specific and practically orientated skills statements (sometimes referred to as 'can-do' statements). But given the intersecting nature of digital skills, it is becoming increasingly important that we gain clarity on the way digital skills are practically applied in a range of contexts. This will be essential to any attempt at defining the essential or foundational components of a digital-orientated curriculum.

The pervasiveness of digitalisation means that there is a vast range of subjects where engineers will have to apply digital skills – many of these outside roles traditionally categorised as engineering. The literature reviewed in this study has covered varied applications where engineers may now need to play a role, including creative media, 3D printing, extended/immersive reality, human–machine interfacing, blockchain, and energy and environmental management[15,21,22,40,41]. Some of the skills required at the interface between digital and other technologies are covered in more detail in Section 4.1.8.

4.1.5 The multidisciplinary nature of digital and data skills

It has been argued that many businesses lack an understanding of how data, and the use of data, can benefit and improve their current practices and growth strategies[25]. Engineers are needed who can combine their data skills with commercial, business, and other technical skillsets which collectively work to unlock productivity. Examples include data governance and information management, strategic application of emerging data technologies, data visualisation, and communication and soft skills, such as using data within teams[24,25,26,42,47]. This mix of skills is still, however, very rare among engineers despite the high and rising demand[25,26,42].

Programming skills were found to be cross-cutting and foundational, and highly cited as an upskilling requirement for engineers, enabling them to deal with developing technology and business changes. They are an essential component of other emerging skillsets, such as managing and accessing data[25,26] and demand is expected to grow as business and industry continue to embrace automation and digitalisation[43]. For example, the increased use of computer-controlled machines and the rise of additive manufacturing are increasing the need for software skills and the ability to adapt machines[7,33]. As with other digital skills outlined in this section, skills gaps have been recognised[44].

In addition to the hard skills associated with programming, such as common or industry-specific programming languages there are also a range of soft skills specific to software development, such as using an agile methodology or communications[45].

4.1.6 Pace of change and adaptability

The pace and extent of change is a prominent feature of the digital transition. Technologies such as AI and machine learning, robotics, computer aided design, virtual reality, quantum, blockchain, and new programming languages are all examples of where rapid developments are driving the need for engineers to accelerate and deepen their professional development on an ongoing basis[7,17,18,20,21,46,47,48]. Much of the literature reviewed here views the changing skills requirements of different industries through the lens of these developing new technologies. This covers the expected technical skills associated with these technologies, but often extends to the broader challenges associated with the dramatic changes the technologies may bring to their operating context, including questions of ethics and regulation. One prominent example is the cybersecurity skills required to adequately protect new digital devices and techniques, especially those that use personal data and are therefore subject to GDPR regulation[15,20,49]. There are skills gaps associated with this requirement that range from basic to advanced technical security[50].

More widely, the pace of change increases the importance of the meta-skill of being able to understand your own upskilling needs, and the ability to adapt to a rapidly changing context[18]. This is covered in more detail in Section 5.2.4.

4.1.7 Artificial intelligence

Artificial intelligence has already started to exert skills demands on engineers, with skills shortages rapidly beginning to emerge[24]. An engineer will increasingly need to manage and understand AI, machine learning, and their underlying concepts[37,49,51,52,53,54,55]. Working with AI tools will also increasingly replace traditional digital skillsets such as programming, digital design, and conventional data security[54].

The effects AI will have on some sectors will be transformative. For example, AI has the capability to maximise the reliability, responsiveness, and accuracy of the UKs entire national energy system. Transformations on this scale will disrupt engineers' existing skillsets as their roles are redefined and as engineers are increasingly required to work alongside AI applications and use AI-augmented skills[37,49,52].

There is also a need for engineers to be skilled in the ethics of AI. Much has been made about the dangers and downfalls of the technology – and arguably less about the opportunities and benefits. Engineers are at the forefront of this change. Businesses need engineers who can explain both its impact and its benefits to wider audiences, including their colleagues and the

public. Engineers with the knowledge and ethical behaviours to manage AI applications are highly desirable to industry and will be required to be ever present as AI extends its reach[49,51,54,56].

Despite the intense debate about AI and digital technologies more generally, they are unlikely to be able to replace human intelligence and skills any time soon. In the meantime, finding the right mix between human skills and new digital applications will become increasingly important to the successful rollout of new technologies. Human characteristics such as creativity and empathy will remain essential, and engineers will need to learn how to work effectively and safely with these emerging technologies. Managers will also be required to maintain a seamless and effective work environment through sensitive governance[55,57,58,59].

4.1.8 Digital/technical interface

As digital skills are becoming increasing relevant across a range of technology domains, their application is often interdependent with closely related technical skills.

Electronics is an example which is growing significantly as it is a key part of the green transition (see Section 5.1.1), which has boosted electrification. The emerging electronic systems are largely controlled digitally, requiring engineers to exhibit a mix of electronics and digital skills often at the expense of mechanical skills. The move to electric vehicles, for example, has created a shift in the automotive industry, with power electronics and software skills increasingly replacing the mechanical skills associated with combustion engines[60].

Engineers will need to adapt their skillsets to meet these new demands with some roles impacted more than others. For example, quality engineers and technicians with knowledge of power electronics will be particularly impacted by the shift to electric systems[61]. Robotic automated systems is another prominent example that is increasingly requiring a combination of digital and technical skills to keep ahead in a highly competitive industry[12,58]. Beyond a knowledge of how to work within digital systems, increasingly engineers will need to deal with nondigital data and how to integrate human requirements within digital technologies.

4.2 Technical

4.2.1 Defining technical skills and shortages

Technical skills lie at the core of engineering and underpin the broader skills discussed in this review. There are persistent and significant issues with the supply of engineering technical skills in the UK, with shortages already evident across many sectors and levels[7,11,13,15,27,62,63,64,65,66,67]. This demand is predicted to rise throughout the next decade[9,57]. This has huge impacts downstream for the UK's absorptive capacity, which is predicted to worsen by 2030 as a result of a shortage of intermediate technical skills[45]. The resulting impact on the economy has been well documented, for example, filling the vacancies in the manufacturing sector alone has been estimated to be able to contribute an extra £7 billion annually to UK GDP[68].

This means that the engineering sector needs to understand how to describe the changing demand for technical skills, and how these skills can be provided.

The main challenge we faced when structuring the information collected as part of this literature review has been how to classify engineering technical skills. These skills cover a vast range of subject areas from programming to the repair and maintenance of manufacturing equipment, and the diversity in these skills is increasing[12]. They can be clustered in several different ways, and it is evident that some skills are highly specific, while others are more cross-cutting. Categorisation is complex and this is reflected across the literature, with studies taking a variety of different approaches. The result is an incoherent picture when considering skills from an engineering-wide, or even broader perspective. This has led to a lack of consensus on the foundational skills that engineers require and difficulties with accurately defining the specific technical skills that are needed[13].

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4.2.2 Practitioners with subject specialisms

Technical skills are viewed as the practical application of subject specialisms. Many reports emphasise 'practical skills', which loosely refer to the ability to work effectively with technologies (using technology as both an end and a means is a dominant aspect of day-to-day work in most industries14). In some cases, this will be a simple matter of having a strong knowledge of the available technologies that can be practically applied, but it can also include contextualising, adapting, optimising, and ensuring correct utilisation, which are commonly cited aspects of these skills[13,18,69,70,71]. However, the exact nature of the technologies being applied varies widely between sectors and subject areas, requiring engineers to situate their practical abilities within a broader subject specialism.

Some of the fastest growing subject areas for engineers are chemical and biomedical engineering, robotics, and simulation[72]. Other prominent subject areas include physics, hydrogen, electrical systems, electronics, medical devices, computer science, and distributed computing[50,55,72].

Subject specialisms increasing in importance include process-orientated specialisms such as lean manufacturing, continuous improvement processes, non-destructive testing, and quality assurance. Quality assurance, for example, includes skills associated with working within a supply chain, and inspecting and auditing processes. This is increasingly important within the manufacturing sector, as underlying materials technologies become more advanced and the related technologies more complicated and interconnected[7,33].

4.2.3 Working with problems

The literature revealed a clear consensus that real-world problem solving, the application of knowledge and skills to address practical problems, is essential across industry. This was a consistent element of employers' views on the top skills needed across different industries[3,10,12,63,59].

Some reports emphasised that many engineers face more intensive requirements for working with problems that extend to 'problem finding' – the ability to surface unseen problems and anticipate future problems and opportunities[5,12]. Closely associated with problem finding and solving are analytical and synthesis skills.

Working with problems is characteristic of a range of engineering roles, from technological innovation to repair and maintenance. This latter topic is becoming especially important as sustainability receives greater attention (see Section 5.1) and there is an increased drive towards extending lifecycles, improving efficiency, and finding new ways of using things[73,74,75,76].

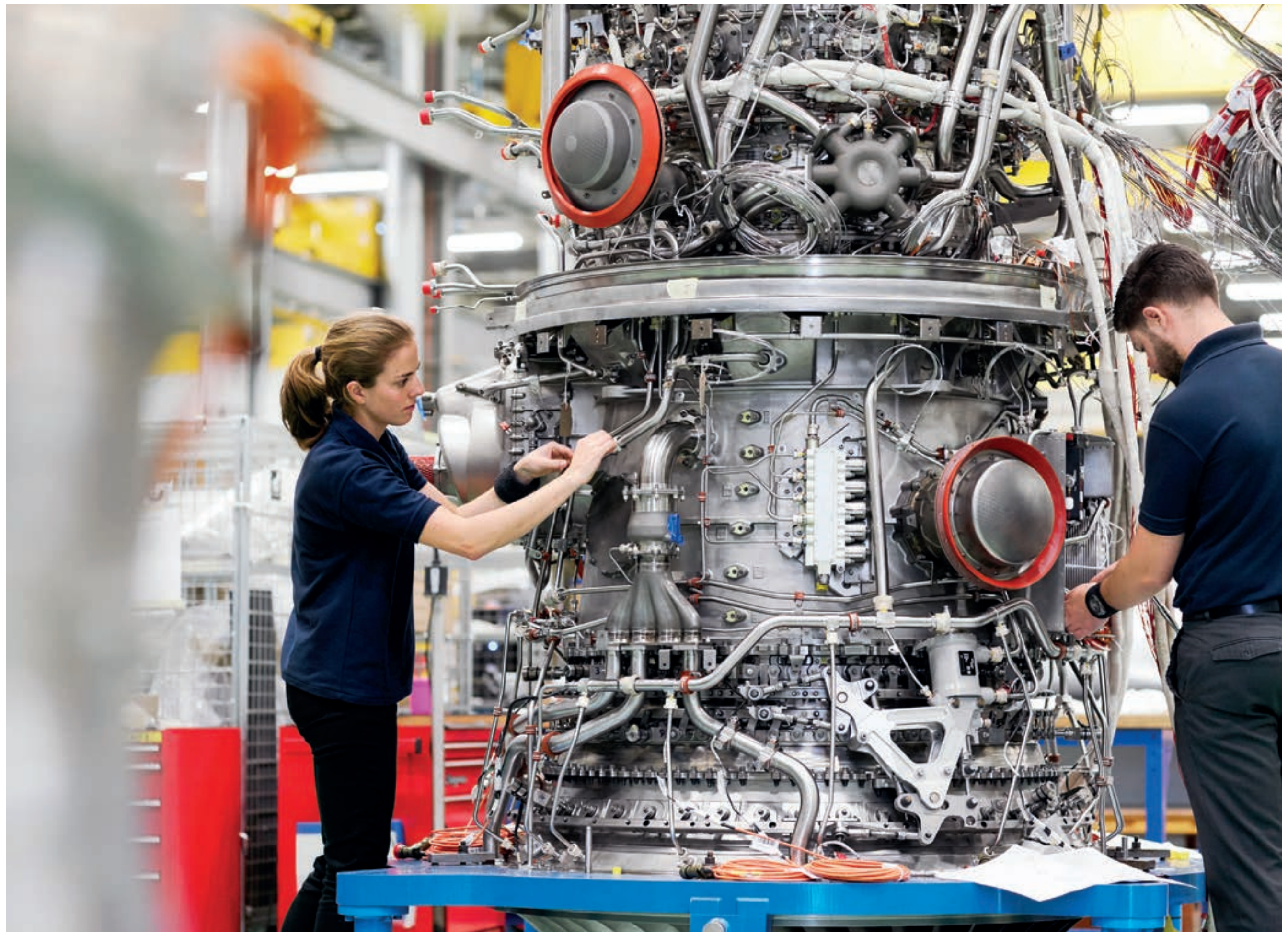
Critical thinking and problem-solving skills are recognised to be, and likely to remain a core aspect of an engineer's role and are often collectively referred to as 'cognitive skills'[65,77,78]. There is evidence to suggest there is a shortage of such skills in the UK[65], especially in some advanced areas such as specialised areas of information technology[63]. As the demand for physical and manual skills is predicted to decline 30% by 2030 because of further automation and digitalisation, and the demand for technological and cognitive skills increase by 50%[14,37,75], problem-solving skills will remain at a premium in engineering.

4.2.4 Creativity and design

Creativity is an important aspect of problem solving, especially alongside analytical thinking[43], and an essential component of ideation.

In a design context creativity is important too and especially during periods of change[12,79]. Although design skills were not prominently covered in the literature we reviewed as a distinct subject, they were often referred to in the context of other skills such as digital, green, data, robotics and automation, computer aided design, and system design skills[7,8,12,20,39]. This was especially the case where there was a requirement for important (and often new) knowledge areas to influence design such as human behaviour, ethics, waste management, safety, circular economy, or whole-life-cycle design[8,9,12,39,58]. It has been suggested that these skills are increasing in importance across companies of all sizes[79].

Creativity is also often linked with innovation (see Section 4.2.6), usually in the context of new and novel ideas. In this respect, creativity as a skill is a uniquely human quality and may become more important as AI (which is perhaps still better thought of as generative rather than creative) starts to dominate the routine tasks that can be automated[12,59].



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4.2.5 Holistic/systems thinking

Being able to situate your work in its broader context, and the impact of your activities as part of a holistic system is another key skill for many engineers and is often referred to as 'systems thinking'. Systems thinking is so fundamental to the way engineers work, that it is often talked about as a behaviour rather than a skill.
It requires engineers to have the ability to recognise, understand, build, and act upon interconnections[5] and is especially relevant in connection with other similar skills such as control engineering which is required for automation, mechanical engineering, and electronics[45].

Systems thinking is a skill that is prevalent across many engineering disciplines and especially important in relation to the major trends effecting engineering – the digital and green transitions – that, as is clear in Sections 4.1 and 5.1, are highly systemic[5,8,11,47,55], as exemplified by topics such as the circular economy[8]. Analysis of megatrends demonstrates a strong future demand for systems thinking[55], but there is evidence of a lack of systems thinking skills in particular sectors, such as electronics and electronic hardware[80].

4.2.6 Combining skillsets: optimisation and innovation

Although the previous four sections on subject specialism, working with problems, creativity, and systems thinking can all be defined as individual skillsets, the way these skills come together often works as a skillset in its own right, especially when combined with project management skills. The primary examples of this are in optimisation and innovation and the combined skillsets needed are becoming ever more prominent as technologies become more interconnected and complex[7,21].

In addition to the skills outlined above, a further skill relevant to optimisation and innovation is the planning, carrying out, and application of development-orientated research[45,79]. This skill is becoming increasingly important as companies' efficiency and growth becomes more dependent on improving production technologies[33,75]. In some cases, this research will be carried out by specialists, but may only be useful when engineers are able to practically implement the findings[45]. The absorptive capacity of a business partly depends on the absorptive capacity of its employees[45].

4.2.7 Cross-cutting skills

In addition to combined skillsets, there are several cross-cutting behaviours and skillsets that are important across much of engineering.

Interdisciplinary and multidisciplinary skills are a prominent example of the cross-cutting skill requirements reviewed here. Interdisciplinary skills refer to the ability of engineers to work well with people with widely different knowledge and skills, whereas multidisciplinary skills refer to the ability of an individual to work across multiple subject areas themselves.

Both have been highlighted as necessary for engineers[81] and are predicted to become increasingly so as the pace of technological change is fastest at the boundaries between disciplines[7,11,62]. Engineers are now expected to widen their skillsets from those traditionally associated with engineering to the broader skillsets outlined in this study[6,12,47,58]. We found a particular emphasis placed on the importance of understanding how different technologies can interact with others from different disciplines and industries, and identifying what future challenges and advances businesses can exploit before others[18,71].

The interactions between engineering teams with other functions in the business are more important than ever, requiring an engineer to be able to take their foundational skillsets and apply them to different parts of the business in a collaborative manner. A data analyst who has commercial awareness, for example, can create wider business impacts[26]. Likewise, engineers that are customer-facing and understand interactions and relationships provide far better outcomes for businesses[58]. So a process engineer may have to combine skills associated with using computer-controlled machines, with a knowledge of where raw material supplies come from, and the post-production finishing processes that are required[7,21]. In some cases, this expands to collaborative working outside of their employer's immediate environment, requiring network-orientated skills[62].

The transferability of skills is something that arises out of the context of cross-cutting skills. Transferable skills are those that may have been developed in one context, but eventually applied to another. They are usually highly valued by employers[77,82], but are especially important during a time of rapid change. Transferable skills ensure that engineers are able to adapt their skillsets to new working contexts across industries[72,82] and provide continued value for businesses[38]. The specific skills that count as transferable are widely defined but include many of the other skills identified in this report including teamworking, time management, communication, and problem solving[39,63,77]. Transferable skills are especially relevant to the green transition[83] where they will underpin successful reskilling and upskilling and are clearly in demand[39].

The interactions between engineering teams with other functions in the business are more important than ever, requiring an engineer to be able to take their foundational skillsets and apply them to different parts of the business in a collaborative manner

5 SKILLS FOR NAVIGATING THE OPERATING ENVIRONMENT

5.1 External context

5.1.1 Sustainability

The most significant external pressure driving the need to inspire, educate, and develop globally responsible engineers is climate change. The need for a just transition for the planet towards net zero is legally underpinned by the 2008 Climate Change act, and formalised in the government's net zero strategy, which sets a target for net zero emissions by 2050. This is the most prominent issue among many sustainability issues that have become impossible to ignore and are the focus of international initiatives such as the UN's sustainable development goals. The need to embed low-carbon solutions, and sustainability more generally into every aspect of business practice and culture is becoming increasingly recognised.

The climate change crisis has been generated because of carbon-intensive technologies. Engineers have an essential role in government and industry efforts towards combatting or mitigating climate change as many of the solutions are technological in nature[86].

Industry is increasingly waking up to the need for a workforce that is skilled to deliver net zero, and that government policy is geared towards phasing out carbon-intensive technologies. Many traditional engineering sectors have begun the process of transitioning. In addition to tackling or mitigating climate change, some literature points to the role engineers will play in finding solutions to specific challenges that will arise because of a warming climate[85].

5.1.2 Global responsibility

The need for engineers to become 'globally responsible' is the dominant message arising from the literature that we have reviewed. This idea posits that engineers should meet the needs of the planet and shape equitable outcomes across all engineering by being responsible, purposeful, inclusive, and regenerative. This requires the skills needed to understand global challenges, how activities impact the world, and how to ensure this impact aligns with the shifting priorities of the public, government, and industry. In some cases, where consensus has not been achieved, this will include the need to navigate tensions and ensure a wider public benefit[74].

As an engineer's work impacts the world in many different ways, the term 'global responsibility' is broadly defined and typically includes an engineer's knowledge, skills, and behaviour in relation to environmental sustainability and climate change; ethics; and equality, diversity and inclusion. The skills issues associated with these topics are explored in further detail in the following sections.

Overarching skills associated with global responsibility include the ability to understand social and ecological systems; whole-lifetime and after-life design thinking; mitigating and adapting; regenerative design and systems thinking; the ability to recognise inclusive approaches and practices; collaborative working with diverse actors; the ability to constructively challenge unsustainable, unethical and unjust practices; and the ability to understand the interplay between solutions, technology, and living systems[74].

To effect change, engineers will need to combine their technical skills with interpersonal skills (see Section 5.2.1) and the passion to advocate for and deliver the necessary change[85]. However, in many cases the impetus to effect change is underpinned by legal obligations such as net zero targets and equality legislation.

5.1.3 Defining 'green' skills by classifying technical skills

The move to a low-carbon, sustainable economy is usually termed the 'green transition' and upskilling the workforce to tackle climate change and reach net zero is often spoken about in terms of 'green skills'.

There is strong consensus that the demand for green jobs and green skills (terms which are often used synonymously) is increasing[86]. Green skills are acknowledged to be important for the development of sustainable transport, clean energy, and sustainable manufacturing[75].

However, in practice the term is used across a very broad range of contexts, including important subcategories such as environment or health and safety[12], and is used in multiple ways by different authors. It also covers skills important to other, broader sustainability issues, such as environmental damage. As a result, the term can present a confusing picture of how, exactly, an engineer might go about acquiring the skills needed to achieve the sustainable development goals[87].

The lack of consensus on how to use the term has been acknowledged, and there have been a few sector-specific attempts at defining green skills in terms of the existing technical skills that will be required to achieve the green transition[23,46,75]. These reports have highlighted a range of specific skillsets that will play into strategies needed to meet net zero targets. They include a vastly diverse range of applicable skills from electronics and turbine maintenance to plumbing, ventilation, and glazing. However, it is not always clear exactly how the demand for these identified skills can be quantified, how they are likely to change, and what kind and level of training is needed[75].

It is possible however, to determine trends in green technical skills at a more general level of detail. For example, to date the green transition has been dominated by particular changes such as electrification and heat management, which have generated a huge demand for skills associated with electronics and electronic control, digital skills[23,83] (covered in Section 4.1) and thermal management[75].

5.1.4 New 'green' skills

In addition to the attempts to categorise green skills in terms of the vast range of traditional technical skills that will play a role in the green transition and the broader sustainability drive, there are some new skills areas that are emerging that are easily identifiable as being green skills – although their exact form, best application, and development trajectory is still an area of considerable debate within the literature. These skills are essential for tackling problems related to complexities associated with the transition.

Examples include net zero assessments and carbon accounting[12,47], sustainable design and implementation[85] (often from a systems perspective), analysis of social and environmental risks[37], low-carbon retrofitting[90], reuse and repair, installation of renewable energy systems and energy efficiency solutions, and specific skills associated with the circular economy and resource efficiency such as whole life costing. To be effective, and to ensure that the changes take place in a way that allows businesses to continue to thrive, these skills need to be applied alongside other skills areas such as governance and strategy development, proficiency with new business models, leadership, project management, innovation, critical thinking, optimisation, communication and business delivery[8,23,27,39,46,75,87,88].

It has also been argued that many established engineering skillsets must be carried out with a broader awareness of the context of the need for sustainability[46]. This may need broad-based, underlying knowledge of the fundamentals of sustainability in practice[88].

5.1.5 A green skills gap

As a result of the changes outlined above there has been a huge increase in the demand for green skills throughout industry, and across all levels, especially within engineering[12]. But there is significant evidence to suggest that supply is not keeping up and businesses are finding it difficult to find the skills necessary to make the dramatic shifts to their working practices that are required[12,15,74,75].

A recent study by The Institution for Engineering and Technology, for example, has found that only 7% of the organisations they surveyed thought that they had all the skills they needed to deliver their sustainability strategies[27].

Specific gaps have been documented for heat pump and heat network engineers, hydrogen and chemical engineers, repairing and maintenance, electric vehicles, and circular economy engineers. These are all needed over the next one to four years to meet the UKs targets and to transition at pace. With many thousands having to be upskilled and reskilled for these new technologies[76,89].

> It has also been argued that many established engineering skillsets must be carried out with a broader awareness of the context of the need for sustainability

5.1.6 Ethics

Another aspect of global responsibility as outlined in Section 5.1.2 is ethics. Engineering is one of the most trusted professions[90] and maintaining high ethical standards will be essential to retaining this status as environmental and social conditions change.

Ethical concerns within engineering have a long history, and the concept of engineers receiving ethics education and training and developing ethics skills is an increasingly accepted requirement[54,91].

These skills are becoming recognised and demanded by government, PEIs, and employers as a result of the well-known social and environmental difficulties associated with emerging technologies[9,54]. It must be noted, however, that the literature is reasonably divided in the way such skills are discussed. Governments and PEIs emphasise the need for ethical solutions and decision-making more generally. Industry's focus though is on areas where there are already widely recognised ethical challenges, and where regulation is already being implemented or discussed – for example, for technologies associated with climate change or AI[56].

At a foundational level, an awareness of the ethical issues associated with an emerging technology – for example recognising bias – is essential[9,18]. This is especially the case for engineers working with controversial applications such as AI[9,56]. But in many cases, this extends to an ability to embed ethical principles and practices into finding engineering solutions, such as ethical design and decision-making, and even ethical leadership[47]. As with other skills outlined in this report, ethics skills will often need to be combined with specific technical skills and so easily accessible materials for practising engineers will be useful.

Ethics principles have been developed for engineering[92], but it has been suggested that such principles need to be developed further, including to an operational level on topics such as design for safety[58]. In addition, several obstacles to the implementation of ethics principles have been noted – including a lack of integration and coordination within the sector that hinders communication and engagement[93].

5.1.7 Equality, diversity, and inclusion

Equality, diversity, and inclusion (EDI) is a recognised part of business practice in most 21st century businesses, in part a result of its legal underpinning through the Equalities Act 2010.

This development is also reflective of the wider change in the culture of engineering, with an increasing number of engineers both noting the imperative to address inclusion within the profession and noting clear improvements.

Perceptions of how inclusive engineering is in practice often depends on whether you are someone with a protected characteristic. Women and minority ethnic engineers, for example, are less likely to say that engineering is inclusive[94].

Low levels of diversity, and difficulty with attracting or retaining women specifically, is a risk to engineering as it hinders the profession's ability to attract the widest range of talent. It is also important that the world made by engineers is an inclusive and equitable one. Diverse perspectives at the design stage decreases the risk that certain end-users' needs are overlooked.

Achieving diversity within engineering is a present and crucial issue and is a clear theme through much of the literature reviewed[18]. Tackling diversity within engineering requires specific business skills, to ensure there are systematic procedures to help employees raise concerns about diversity or malpractice[18], to maintain an equitable working environment, and foster appropriate behaviours and mindsets within the wider staff. Improving the diversity of the engineering workforce is also recognised as one way of tackling the skills gaps that have been flagged under the various sections of this report.

5.1.8 Regional and sectoral variability in skills required

The external pressures outlined above impact all engineers to some degree. However, the requirement for associated skills varies considerably on a regional, sectoral, or industry-specific basis[95]. Some challenges are particularly acute for certain sectors or regions[12].

For example, manufacturing, as one of the UK's most polluting sectors, has a widespread need for engineers with sustainability skills – especially if the sector is to meet its net zero targets[15,29]. And yet this sector demonstrates a particularly large green skills gap[27]. Civil engineering, too, is experiencing a large growth in the demand for green skills[12].

With respect to regional variability, London and the Southeast have a higher intensity of high value, innovative engineering. R&D intensive activity tends to focus on cities, with associated 'near-city' enterprise zones in the connected towns and rural areas. Engineering also does not play much of a role in the economies of many rural areas[96]. All these factors influence the engineering skills that are in demand in a particular location.

The changes needed to meet net zero targets are also recognised to impact regions in different ways, giving rise to the call for a 'just transition'. Yorkshire and Humber, for example has a large concentration of jobs in carbon-intensive industries[96]. At the other end of the spectrum, some regions have been quick to embrace the coming changes and are relatively better prepared. An example of this is that green skills training provision is much higher in London than elsewhere in the UK[27].

5.1.9 Communication with the public, policy makers, and clients

Many of the changes outlined in this section demonstrate the increasing interlinking of private and public concerns. This has resulted in an increased demand for engineers to develop communication and public engagement skills[47,85]. Although communication skills are often talked about as a soft skill, a distinction is being increasingly made between communication skills relevant to the workplace (for example as associated with team working, management, and leadership – covered in Section 5.2.3) and the skills required to communicate with the public, policy makers, and clients.

Such 'external' communication skills include 'critical media literacy', which is required for effectively engaging with the political, social, and economic challenges associated with new technologies or technical solutions to well-known issues[18,86,97]. Sometimes the target audience is the market for new products and services, or clients who might need to understand why particular changes to established practice are needed[90,98]. Given the pace of change, and magnitude of impact associated with many of these challenges, these skills are often presented as not only important but essential.

In particular sectors, such as big data[29] and sustainable technologies[90], it has been suggested that the challenge has become so acute that it has engendered the distinct skills requirement of being able to work in the face of misinformation. This includes identifying misinformation, generating and presenting data in a way that tackles it, and radically engaging the public to help combat associated issues[18]. This skill will be important if engineering is to remain a trusted profession[91].

It has also been suggested that the public does not yet have an adequate understanding of the importance of green skills to businesses, their wide applicability, or even an awareness that they are in demand[60,99], even in the face of a strong motivation among young people to develop skills in this area[100].

5.1.10 Resilience and adapting to change

Agility – the ability to adapt rapidly, transferring and adapting traditional skillsets to new operating contexts – is a widely recognised skills requirement enabling industry to respond to change[54]. It is a theme that has come up frequently in the other sections of this review. A closely related concept is resilience – the qualities required to continually respond to change.

To be prepared for future changes that we are not able to fully predict, it is important to foster this kind of agility. Some literature suggests that more emphasis should be placed on transferable skills, such as creativity and critical thinking, and how these can be applied across a range of applications, rather than a too heavy emphasis on current technical skills[39,87]. This may leave particular employees vulnerable to change and industry without a sufficiently adaptable workforce. A similar suggestion is that a broad knowledge of the fundamentals of a particular area (for example, sustainability and sustainable practice) should be encouraged alongside an innovative mindset[88].

5.1.11 Regulation

New or amended legislation and regulations for new technologies such as AI, data, and the transition to net zero[12,41,100] have accelerated the need for engineers to have skills in understanding regulatory environments and associated issues facing these emerging technologies and changes to the way engineering is engaging with society[47]. Many of these new technologies are facing questions on their impact on society and workers and the need to regulate them by governments. Engineers who understand regulation alongside problem-finding skills (see Section 4.2.3) early in their careers are in demand by industry to help them foresight the challenges they may encounter when they bring products and services to market.

5.1.12 Negotiation and compromise

Engineering and engineers are now becoming part of the broader workstream for many industries and thus are encountering different ways of working, thinking, and practising that they may not be accustomed to – including complex and competing demands from clients. Evidence encountered in this review highlights the need for engineers to have the necessary negotiation and compromise skillsets to tackle these differences and engage with the complex and competing outcomes that they are facing[42].

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5.1.13 Cultural skills

The engineering challenges shaping the world today and in the future are not limited to just the UK. Many of our industries are global businesses with international supply chains and many of the solutions required to meet these challenges are global. Therefore, business and industry are looking for (and not always finding) engineers who have the cultural skills necessary to carry out their work in these different environments[82].

On a larger scale, the influences that have shaped world cultures include the dominant technologies that have structured the lives of people in different places and times. The constant and accelerating pace of technological change, along with the existential challenges facing all of humanity, will require significant cultural changes across the world. Understanding how to effect cultural change is an essential component of ensuring that new technologies are implemented and embraced[86].

5.2 Internal context

5.2.1 Defining soft skills

Many of the nontechnical skills that businesses use in their internal operations are referred to as 'soft skills'. They are generally considered to be essential to employability but not immediately or obviously linked to an engineer's primary role. However, many of the reports we have reviewed talk about the importance of various kinds of soft skills – especially in the context of the huge changes facing the sector.

5.2.2 The business context

Most practising engineers work within a business context. Likewise, businesses depend on engineers to succeed and grow. However, some reports have suggested that there is a shortage of engineers with business skills who can achieve both the technical and business outcomes needed[7,26,79]. This is especially true in the context of new technologies such as quantum – of which many in the business community have very little understanding nor appreciation of its implications. Engineers are being looked at to have the necessary technical skills, but also critical thinking, entrepreneurial, project and change management, customer engagement, horizonal leadership, and interview skills to communicate with these different audiences[19,38,47,99,101,102].

Important soft skills for working within a business context include the ability to negotiate trade partnerships, teamworking, project management, time management, prioritisation, customer handling, resilience, and flexibility[8,12,13,23,27,63].

In a similar way, many innovative new lines of productive business happen in startups and new businesses. The small size of these companies places a special pressure on engineers to develop wider entrepreneurial skills. These kinds of skills are important whenever businesses require engineers to capitalise on the changes happening in the engineering industry[103]. Many of the reports reviewed here highlight that the need for entrepreneurial skills will increase in demand over the next decade to help industry take advantage of the new products and R&D currently being undertaken[104,105].

Risk management is also an important tool in an engineer's kit. This is especially true in areas of rapid change, such as AI[86], where engineers are required to risk assess changes, and understand how changes can be safely implemented and used. Likewise, the green transition is requiring better risk management skills that enable engineers to deal with hazards that have not been tackled by engineers before, such as climate impacts, health and safety, and loss of biodiversity[12,37].

5.2.3 Organisational structures: working with people

The importance of engineers to successful business strategy and practice increasingly means that engineers will need to take on leadership roles[12,69]. Management skills (both project and team management), prioritisation, strategy development, and communication are therefore a necessity[54,57,75]. Industry wants engineers who can move up through the business they are in. Helping to manage other employees' skills alongside the deployment of new technology is an important leadership skill for engineering projects[12,62,72]. These skills have been loosely collected into a concept of 'engineering management' which is distinct from regular management and in high demand[12].

Despite automation, businesses depend on people, and so skills, that enable optimum human interaction – especially during dramatic transitions in working practices. This requires engineers to have social and emotional skills such as empathy, responsibility, self-efficacy, and the ability to collaborate, and reports have suggested that the importance of these skills will increase as the decade progresses[14]. Such emotional awareness allows engineers to enhance their leadership and relationship skills[78].

Workplace communication skills (which are distinct from the public-orientated communication skills outlined in Section 5.1.9) have come up as especially important – particularly professional written and verbal communication skills[73,106]. In the workplace engineers with the skills to establish and maintain relationships, make decisions, and listen are becoming the top skills businesses look to develop[60,73]. This has partly been accelerated by the introduction of remote and virtual working with digital platforms becoming a primary communication channel for much of the workforce[18,48].

There is also a growing need for engineers to communicate, explain, and sell the different technological changes happening within their workplace to those that may not have a technical background. This including management colleagues who need to be kept up to date with advances happening in other parts of their company or other industry operators[12,25,36,38,99].

5.2.4 Meta-skills and self-assessment

Many industry reports commented on the need for, and lack of, engineers who work with the appropriate attitudinal skills in the workplace[33]. This can include adapting to changing circumstances, managing frustration, knowing the limits of your own knowledge and skills, and delegating and collaborating effectively[23,35,38]. Some reports link this concern primarily to students coming into the workplace without the character or habits they need to work effectively[5,35].

> There is also a growing need for engineers to communicate, explain and sell the different technological changes happening within their workplace to those that may not have a technical background

One of the main contradictions found in this review was between the views of students versus employers on skills requirements. As mentioned in Section 4.1.3, digital skills is a prominent example of this. Students that have lived in a digital world from birth often believe they have the digital skills necessary for work. However, while employers admit such students are often more digitally savvy, they find them to have been passive consumers rather than active users of digital technologies, lacking the core skills needed to take advantage of new technologies being developed and implemented[25,60].

Some studies suggest that industry considers students not to be prepared for the realities of work or without experience of the corporate environment that they desire[27,38]. Engineers are required to develop skills appropriately as their careers develop. With the skills needs of industry continually in flux, future skills needs remaining uncertain[107], and with the skills gap in many sectors widening, industry is looking for engineers who can navigate their own choices and abilities around their work. The skills needed for effective self-assessment – where an engineer can appropriately assess what skills they have and what skills they will need in the future is therefore highly desired[11,18]. Industry has begun to look for engineers with the skills to self-select learning opportunities that allow them to progress in their career[37]. Such meta-skills alongside the ability to learn are becoming some of the demanded skills, with over three-quarters of manufacturers expecting that demand to increase[14,108].

It is also important to consider the skills required to navigate one's own choices around the working patterns and styles of colleagues[11]. This requires deliberate self-reflection and self-assessment of team productivity, as well as skills in communicating with others for optimal coordination[18].

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APPENDIX A – METHODOLOGY

The method applied in the development of this literature review is outlined in the following steps.

1. Literature scope

The scope for the literature was established as follows:

In scope:

- Literature discussing new emerging skills needs facing future engineers.
- Material published within the last five years (for certain high profile reports, a time limit of 10 years since publication was applied upon agreement from the team).
- Grey literature and government papers, not academic studies or media articles.
- Material sourced by academies, PEIs, employer-representative bodies, membership bodies, government strategy, government commissioned research and consultations, and arms-length bodies.
- Engineering-focussed reports make up 80% of the review.
- Reports must be future-focussed, rather than an assessment of current need (unless such assessments are used to articulate trends).

Out of scope:

- Academic studies (this work focuses on grey literature).
- Knowledge/skills statements (this is too big a question for this literature review and will require further dedicated work, including detailed commissioned studies).
- Ecosystem requirements more generally.
- There will be no new data analysis carried out for this work.

2. Stakeholder list

A stakeholder list was developed to identify organisations likely to be publishing in-scope literature. This list consisted of 180 engineering and education and skills stakeholders.

3. Evidence library

The websites of these stakeholders were explored, and soft copies of in-scope literature downloaded into an evidence library using a standardised file naming system. As part of this process 118 reports were collected.

4. Evidence distillation

Each report meeting the eligibility criteria stated above was reviewed by a member of the education and skills policy team. Evidence distillation consisted of extracting succinct evidence statements relevant to Engineers 2030 from much longer more in-depth reports. An evidence statement was required to meet the following criteria:

- It must be related to a technological/economic/social need that is likely to persist into the future or worsen.
- It must be qualified by a clear evidence-based observation, trend, concern, or recommendation.
- It must be linked to a clear skill, knowledge area, behaviour, or quality of a future engineer.
- The statement must be expressed in as simple terms as possible.

Evidence statements were collected using a template consisting of a table with the following fields:

- organisation
- report title
- skills statement
- evidence (including references)
- initial categorisation.

If a particular evidence statement was already recorded from another report, it was still recorded. If a particular skills need was covered in multiple reports, this was be considered during the evidence synthesis phase.

During the evidence distillation phase, 352 separate evidence statements were collected.

5. Evidence synthesis

Evidence statements collected in the evidence distillation process were clustered into groups based on the initial categorisation assigned. These groups were then arranged into themes that aligned with a potential narrative structure for a report, with changes to categorisation made as necessary. Each narrative section was then reviewed following the following process:

1. Identify any skills need statements that essentially make the same point.
2. Identify from the supporting evidence whether the skills statements identified in Step 1 arise from the same evidence source. If so, combine the statements and evidence statement into one, referencing only the original work. If not, combine the statements but add separate lines for the supporting evidence and reference all lines.
3. Identify any skills need statements that contradict each other, or whose supporting evidence is not coherent.
4. Critically analyse the supporting evidence for skills statements identified in Step 3 and make a case for one or the other.
5. The case developed in Step 4 should be reviewed by other team members before a final decision is made. Remove the least convincing statement (keeping it for reference in a separate document).
6. Identify any skills that are linked by causal logic and group them together.
7. During any of the above steps, it may become apparent that a particular skills statement fits better in a different skills grouping. In which case, it should be moved.

A narrative is developed that covers all the skills statements in a particular section.

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Royal Academy of Engineering
Prince Philip House
3 Carlton House Terrace
London SW1Y 5DG

Tel 020 7766 0600
www.raeng.org.uk
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