A Review of the Digital Skills Gaps in the Advanced Manufacturing Industries

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Executive summary

The purpose of this report is to analyse the Digital Skills Gaps in the Advanced Manufacturing Industries, in order to understand how the Institute of Coding, and Higher Education Institutions delivering computer science, can help to close these skills gaps by providing up to date and relevant HE programmes at Level 6 and Level 7.

Advanced Manufacturing is the combination of information, technology and people, to add value to a manufacturing business or sector.Closely related to ideas such as Smart Manufacturing, Industry 4.0, and Industrial Digitalisation, Advanced Manufacturing builds on the agile, flexible and computer integrated manufacturing of the last 20 years.

Advanced manufacturing goes beyond traditional manufacturing, such as turning, milling, drilling, for example, using laser processing multiple axes machining with better accuracy on machining, improved process control, and less variation from part to part. It also encompasses measurement and analysis of the product, and software systems also help to advance the manufacturing process, for example bringing together CAD and CAM.

Advanced Manufacturing is applied in a range of sectors, from Aerospace to Wireless Technologies.

This report is an analysis of the skills gaps in the UK's Advanced Manufacturing Sector. It examines a range of previous reports in order to understand digital skills gaps and looks at ways in which they are being filled. It defines some of the main features of the sector, and discusses digital skills, and some of the reports that have already been undertaken in this area. It examines a total of 46 technology trends that are associated with the advanced manufacturing sector, all of which require some level of digital skills.

The report includes some discussion around the different ways in which digital skills are defined, considering basic digital skills vs hard/advanced digital skills. It is generally considered that advanced digital skills are required to fill the digital skills gaps in advanced manufacturing, and these will be obtained by studying for a degree level qualification (either through University Degree or Degree Apprenticeship), although some can be achieved at level 4 or 5. The skills gaps are not static and education providers need to be prepared to deal with relatively rapid changes in order to continue to address the skills gaps of the future.

The existing digital skills gaps are examined per sector, and some discussion of the ways in which the HEIs, and others providers, are addressing the skills gaps. This includes some consideration of models of delivery, asking the important question as to whether current university provision is flexible and agile enough to affect any meaningful change.

Finally some recommendations are made for universities, and for employers. These focus around the need for adequate communication between HEIs, government, and employers, the need for flexible delivery, the requirements for workplace learning of various types, and the need for course development to be agile, thus being able to respond to fast changing needs. There is also the importance of addressing local needs, by co-development with other local stakeholders, such as local government, chambers of commerce and LEPs .

As in any analysis of skills gaps, there is no silver bullet, but it is clear from this research that there is a demand for digital skills by employers, and a willingness for HEIs to develop relevant courses to provide these skills, there are also sufficient numbers of HEIs in the Institute of Coding to make an impact. Whilst there is a need for some increased flexibility agility, the right types of training and education exist in order to meet the skills gaps in the short term and in the longer term, and it is a combination of all of these approaches that will go some way to addressing the problem.

Note:

The original report by Conbrio Associates was a desk based survey, and represents a snapshot of the Advanced Manufacturing Sector as of August 2019. Much has happened in the world since then and we face a significant challenge to our economy as we recover from the Covid-19 Pandemic. Much of what we do as educators and trainers is to provide the skills necessary to grow the economy of our nation, and therefore the work to be carried out in Advanced Manufacturing needs to be seen as an opportunity to have a positive impact on an economy that has changed dramatically in just a few months.

1. Introduction

This report presents a summary and analysis of the evidence collected and produced in a report carried out by Conbrio Associates in August 2019, on behalf of the Institute of Coding and Manchester Metropolitan University (Conbrio, 2019).

The report starts by analysing the term Digital Skills, and some of the contexts in which it is used, with a particular emphasis on the advanced manufacturing sector. It then goes on to provide a summary of what is generally considered to be the advanced manufacturing sector looking at what advanced manufacturing is defined as, and some of the technology trends that appear to make up the sector.

Later in the report there is an examination of the evidence presented in a number of papers, articles and reports relating to the current digital skills gaps. It looks at the courses being offered by universities and other ways in which the HE sector is looking to address the skills gaps. There is some interesting comparison made between the technology trends and the courses being offered by universities, based on their titles, both at undergraduate and postgraduate levels.

Finally the report makes some recommendations as to what now needs to be done in order to have a serious impact on reducing the skills gap, not least of which is maintaining an active perspective on the needs of employers and the creation of courses to match these needs.

The aim of the report is to examine what constitutes the digital skills gaps in Advanced Manufacturing, and to relate these to the provision of digital skills education in computer science at HEIs. It will also consider other mechanisms for closing these skills gaps.

2. The Advanced Manufacturing Sector

The term "Advanced Manufacturing" has been defined slightly differently by a number of commentators and researchers. However, Paul Fowler's (2010) definition of Advanced Manufacturing 'Entities' is commonly repeated. He is cited as stating that an advanced manufacturing entity is one that:

"makes extensive use of computer, high precision, and information technologies integrated with a high-performance workforce in a production system capable of furnishing a heterogeneous mix of products in small or large volumes with both the efficiency of mass production and the flexibility of custom manufacturing in order to respond quickly to customer demands." (IDA, 2010)

Any definition needs to be technology agnostic, as the technologies applied will change rapidly with time. There is, however, a focus on technology and skills in most definitions, and these are the main focal points of this report. The skills will not always be technical, and the workforce of the future needs to be as agile and adaptable as the sector in which it is employed.

For the purpose of this report, we define the family of high tech or medium-high tech industries that utilise advanced manufacturing in mid 2019 as including: Aerospace; Electrical, Electronics and Computing; Healthcare/Pharmaceutical; Automotive; Energy; Military and Defence; Construction and Infrastructure; Food and Drink; Oil and Gas; Chemicals. This is not an exhaustive list but is certainly representative, showing the breadth of manufacturing that digital skills are being applied to. Textiles may also be considered an important industry, given it's key role in the fashion industry and the scale of pollution it produces. We are looking at the skills required to apply digital technologies to the manufacturing princess, and the application of digital skills to produce high tech products.

The Fourth Industrial Revolution

The fourth industrial revolution, also referred to as "Industry 4.0" and "i4.", is defined by a report by McKinsey (Baur and Wee, 2015):

"...the next phase in the digitisation of the manufacturing sector. It is driven by several factors: the rise in data volumes, computational power, and connectivity; the emergence of analytics and business intelligence capabilities; new forms of human-machine interaction such as touch interfaces and augmented reality systems; and improvements in transferring digital instructions to the physical world, such as advance robotics and 3D printing. (Baur and Wee, 2015)

The report also suggests that change is happening 10 times faster and at 300 times the scale, when compared with the first industrial revolution.

Industry 4.0 is also defined by Henrick von Scheel, who describes it as "the most disruptive period in human history" where the digital, physical and virtual worlds collide (also referred to as cyber-physical systems. He suggests that we are in the 2nd of three waves, where AI, blockchain and 6G communications are some of the key enabling technologies (von Scheel, 2020).

The Boston Consulting Group (Gerbert, et al, 2015) describe nine technologies that they believe are transforming industrial production. These include augmented reality, big data analytics, cybersecurity and cloud computing.

The earlier definition of Advanced Manufacturing focuses on manufacturing itself, rather than some of the wider technologies that Industry 4.0 has picked up on, such as the use of Augmented Reality and Digital Twins for factory layout, or supporting service and maintenance. It is clear that our definition of Advanced Manufacturing and subsequent analysis must include Industry 4.0 and its enabling technologies.

Smart Manufacturing/Cyber-Physical Systems

The manufacturing element of the fourth industrial revolution has been termed "smart" manufacturing, or cyber-physical systems, where machines collaborate with humans, rather than simply being controlled by them. It can also include situations where machines make use of AI or Machine Learning to "think" for themselves, or are autonomous, but it is digitally-sophisticated humans who ultimately create the technologies and the programs that drive them. Smart manufacturing makes extensive use of technologies such as sensors, big data, simulation, digital twins and the Internet of Things (Conbrio 2019). There is also extensive use of the cloud, and cyber-physical systems require fast communication technologies, such as 5G.

"Smart factories" are those that incorporate the various facilitators of the fourth industrial revolution, or Key Enabling Technologies (EC, 2016) . They often feature shorter production runs, more complex machines and closer integration with supply chains. They may attract customers whose requirements might change at irregular intervals and with short notice. Typical applications are cited as including:

"computer-aided design (CAD), computer-aided engineering (CAE), flexible machining centres, robots, automated guided vehicles, and automated storage and retrieval systems. These may be linked by communications systems (factory local area networks) into integrated flexible manufacturing systems (FMS) and ultimately into an overall automated factory or computer-integrated manufacturing system (CIM)." (OECD 2012)

Digitalisation

Digitalisation is the application of digital technology and data to transform operations and add value to a business (Ezell, 2019). The Heart of The South West LEP (HoSW, 2018) makes reference to digitisation and digital skills stating that:

“Digital technology is creating the need to completely re-engineer businesses requiring firms to make changes to their organisations, skillsets, processes and introduce new systems and new business models. This makes digital transformation a challenge for many firms especially those without the necessary skills in the management and leadership teams.”

Industrial Internet of Things (IIoT)

The Industrial Internet of Things (IIoT) is the application of IoT technologies and concepts to an industrial setting, taking into account the particular needs of industry as opposed to the needs of consumer, domestic and business settings (Boyes, et al 2018). IIoT applies across a range of industry sectors, including manufacturing, and is enabled by the use of technologies such as cybersecurity, cloud computing, Edge computing, big data analytics, AI and machine learning.

3. The Digital Skills Gap

The term digital skills is used in different ways and can cover a wide range of skills and activities. When employers speak of digital skills they will often include soft skills, and may be referring either to basic digital skills or sector specific, advanced digital skills (Kispeter 2018). Many of the reports and articles do not elaborate.

In 2017 the British Chambers of Commerce reported that, whilst UK firms felt that digital skills were becoming increasingly important to their business, more than 75% of them faced a shortage of digital skills. The most commonly required skills were:

- basic computer skills
- communicating and connecting through digital channels
- management of digital information (BCC, 2017)

Defining Digital Skills

The OECD (2012) suggests that four types of digital skills are necessary in the workplace:

- ICT generic skills - the use of digital technologies for professional purposes, such as accessing information online or using software;
- ICT specialist skills - skills needed for the production of information technology products and services (such as programming, developing applications, managing networks;
- ICT complementary skills - skills for performing tasks associated with the use of ICT, such as information-processing, self-direction, problem-solving and communication;
- Foundation skills - digital literacy, emotional and social skills enabling the use of digital technologies.

Drawing on results from their annual survey of enterprises, Manufacturing Skills Australia (IBSA, 2018) identified a similar set of four major skills needs for the manufacturing sector. They suggest that the in demand employability skills can be divided into soft basic skills, and hard basic skills. The distinction seems to be the specific nature of the hard skills, and the more generic nature of the soft skills. None of these are specifically digital skills, but they are skills that we would expect a skilled practitioner to possess, and these would be the Foundation skills described by the OECD (2012).

Soft Basic Skills

- ICT generic skills - the use of digital technologies for Social perceptiveness and instructing
- Speaking and management of personnel resources
- Monitoring, supervision, coordination and time management
- Critical thinking, judgement, negotiation and persuasion
- Reading comprehension and quality control analysis
- Active listening
- Writing

Hard Basic Skills

- Service orientation, system analysis and operation monitoring
- Mathematics, Science, Complex problem solving and Learning strategies
- Quality control analysis, systems evaluation and troubleshooting

Innovation and Business Skills Australia (IBSA, 2018) quote the Boston Consulting Group, which considers that "workers will need to combine the knowledge related to a specific job or process, with IT competencies 'that range from basic (using spreadsheets and accessing interfaces) to advanced (applying advanced programming and analytics skills)'.

The BCG also notes that simple tasks will be taken over by robots as factories and supply chains become increasingly digitised; and that humans will need the skills to oversee these tasks. (IBSA, 2018)

Hard Digital Skills

LinkedIn Learning (LinkedIn Learning, 2019) list the skills people are asking for, dividing them into soft and hard skills. Their top five "hard skills" are mostly digital skills:

1. Cloud Computing
2. Artificial Intelligence
3. Analytical Reasoning
4. People Management
5. UX Design

This is updated for 2020 (LinkedIn Learning, 2020) and includes Blockchain as the most important, and people management dropping out of the top 5. This demonstrates the public perception of the in demand digital skills across a range of employers (not just advanced manufacturing). These lists are not specific to manufacturing but are of interest as they show that there is a crossover with the digital skills being sought by manufacturing organisations.

Looking at some of the specialist skills and complementary skills, a report from the Heart of the Southwest LEP listed the following jobs being identified by employers as being in the greatest demand (HoSW, 2018):

- Data scientists
- Software engineers
- UI/UX designers
- Strategic skills for digital transformation
- Senior java developers
- Azure skills
- Cyber security staff
- Data analytics
- Experienced staff in cloud integration
- Computational Fluid Dynamics (CFD)
- CAD and Computer Aided Engineering (CAE)

The Made Smarter Review is a significant piece of research that is reflected by much of what is in this report. The review produced a skills matrix for currently used technologies, currently required technologies, and future requirements. These were developed as a result of interviewing individuals in the advanced manufacturing industry, and it should be noted that they indicate it is a snapshot that should be regularly updated.

The main areas where digital skills can be identified in the existing skills matrix are listed here but, arguably, all of those skills include some elements of digital skills:

- Software development
- Data Processing
- Systems Development (robotics)
- PLC Programming
- System installation and setup

However, when looking at the in demand skills, and future skills, there is a clear shift to digital skills, and these give a good indication of where the industry believes the skills gaps will lie. The three skills matrices from the Made Smarter review are reproduced in Appendix C.

Digital Skills Likely To Be Needed In 2020

Many present-day digital jobs didn't exist ten years ago for example, app developer, social media manager, cloud computing specialist and big data analyst (WEF, 2016; Edge Foundation, 2018; Alpha, 2016). With the WEC stating that 65% of children entering primary school will end up working in jobs that aren't on our radar yet.

In The future of work in manufacturing (Deloitte, 2018), Deloitte suggests that technological advances will create a number of presently unfamiliar roles. These roles stress the elimination of routine activities by automation, resulting in more time to develop both hard and soft skills and processes that involve collaboration with AI and robotics, linked by data flows.

In addition to the predictions in the Made Smarter Review (Maier, 2017), Deloitte's Tech Trends (Deloitte, 2019) lists the following expanding digital areas:

1. Artificial Intelligence
2. Cloud Computing
3. Connectivity and networking
4. Human-machine interfaces
5. Personalisation: CMOs and CIOs are partnering to deliver highly personalised, contextualised experiences enabled by new marketing tools and techniques
6. Security: DevSecOps fundamentally transforms cyber and risk management from compliance-based activities to essential framing mindsets.
7. Digital reality: e.g. augmented reality, virtual reality, mixed reality, Internet of Things
8. Cognitive technologies: e.g. machine learning, neural networks, robotic process automation, bots, natural language processing, artificial intelligence.
9. Blockchain.

Some of these are considered part of the current digital skills gap, but some could form the digital skills gaps of the future. Richard Coombes, leader of HR transformation at Deloitte, commented that "Digital skills are not a static set of skills. We live in a world where the half-life of a technical skill is two-and–a-half years at most." He also stressed the importance of lifelong learning, and that business should have a learning and development programme that fits their digital strategy (Deloitte, 2019). So whilst we may not know the future with any certainty, we do know how to deal with it.

Changing Nature of Digital Skills

In addition to the advanced digital skills, modern employees will be required to be "even more open to change, possess greater flexibility to adapt to new roles and work environments, and get accustomed to continual interdisciplinary learning" (IBSA, 2018)

Interviewed in the Heart of the South West LEP survey (HoSW, 2018), one employer explained, "The blend and mix of skills has changed, we now want data knowledge sometimes with domain knowledge. We need staff who can write code and algorithms." A number of interviewees mentioned the importance of 'cultural fit' and the importance of having the foundation skills on which to build: "The business has changed and the market has changed, we used to need technical skills now it is more about attitude and creativity and fitting with the culture of the company" Skills needs are changing so fast that adaptability and a willingness to learn is key. It is important, also to recognise that fitting in with a culture should mean a culture of diversity and change, rather than fitting into a fixed existing,and unchanging business culture.

The World Economic Forum 2016's Future of Jobs survey determined that 35 percent of the skills deemed important in today's workforce will have changed in four years.Unsurprisingly they identified the ability to work with data and make data-based decisions would play a major role in the jobs of the future. They went on to suggest that creativity, complex problem solving, and critical thinking would be the top three broad skills that people would need for Industry 4.0. (HoSW, 2018).

4. Technology Trends In Advanced Manufacturing

Advanced manufacturing encompasses a wide range of activities and the trends that include digital elements are numerous, with many being entirely dependent on digitalisation. The trends (see Appendix A) will require advanced digital skills in their creation, development and implementation and are, therefore, vulnerable to digital skills shortages. They also usually require that those that make use of them and manage them have high levels of digital understanding. One of the challenges facing the advanced manufacturing sector is maintaining and enhancing the digital awareness and knowledge of executives and managers so that companies can make best use of evolving technologies.

These trends are present in multiple industries and challenge organisations both large and small. Others, though in themselves specialised, involve digital skills that are cross-sector. Some trends, (e.g. AI) are very broad and have different meanings within different industries.

It is useful to compare this list of technology trends with the available courses offered by universities. In addition there may be courses offered by other training providers. It is also not clear from the list as to whether these trends can be understood using shorter Continuing Professional Development (CPD) courses alone or whether longer term higher education programmes are required.

Some analysis on the alignment of these trends with courses from UK universities has been carried out (Conbrio, 2019) and is presented in Section 8. It is an analysis of the keywords in degree titles, and it suggests that there is not a close match between the trends and degrees offered at present by UK universities. It is a fairly superficial analysis, but it does give an indication as to why employers feel that their skills needs are not being met. This perception will also be held by potential students and career advisors, who do not fully appreciate the details behind course titles. Many university websites only provide a superficial description of the course content, and so it would suggest that there is a requirement for better signposting of which skills are being developed, and where.

An example of how this is being addressed, the MSc in Industrial Digitalisation in PrintCity (located at Manchester Metropolitan University) established a focus group to inform the curriculum. This included people from Bentley, Autodesk and Siemens amongst others. An agreement was made with both Siemens and Festo for a programme where students gain access to a wide range of software from CAD, process simulation, factory layout simulation, etc., along with tutorials, training materials and case studies. This allows academics and students to work with state of the art software that is widely used in industry making the courses more relevant for students and preparing them for employment.

The presence of a strong Industrial Advisory Board at Manchester Met is supporting such developments, where close to 40 members, are invited to offer live projects for students, to attend open days and visit days, work together on outreach programmes and recruitment, and giving guest lectures, all of which can improve the student industrial experience whilst at university.

5. Analysis of Digital Skills Gaps

This section looks at the digital skills gaps for a cross section of Advanced Manufacturing Sectors. It will act as a starting point for a deeper understanding of each of these sectors, and it is recommended that a more focussed analysis is carried out for each.

In addition there is some brief analysis of the digital skills gaps in STEM, which are widely reported and are the bedrock on which Advanced Manufacturing is built.

The report produced by Conbrio also includes some analysis of the skills gap in Cybersecurity, which is a gap that is reported across industries, sectors and regions, and is being addressed by many initiatives across the UK. Additionally that report provides some discussion of the lack of gender diversity in manufacturing, which may not directly address the skills gaps but will provide a more appropriately diverse pool of talent through which the skills gaps can be addressed.

The Digital Skills Gap

The Oxfordshire Skills Strategy (OxLEP, 2017) provides some useful information, and reports that locally, most skills gaps are occurring in high and middle skill roles, and that 73% of manufacturers in the country have faced difficulties recruiting skilled workers in the last three years. They put this down to a lack of technical skills, an insufficient number of applicants and a lack of relevant experience.

The Strategy also reports that the number of 'hard-to-fill' vacancies overall in the UK remains static at around 35 per cent, and as a result, 79% plan to recruit manufacturing and engineering apprentices in the next 12 months.

The Open University suggests that lack of skilled staff is making businesses less agile and cites data from the Cardiff Skills and Employment Survey 2017, which suggests that the take up by employees of on-the-job and general training levels have fallen and that the number of jobs requiring a university education may have plateaued. Which is interesting as it is at odds with the many other reports that have been produced around the digital skills boom for Industry 4.0. The Cardiff Skills survey is a survey of employees, and it perhaps reflects the high levels of employment in the UK, rather than the lack of skills requirements.

The Edge Foundation (2018) also reports on a survey by the British Chambers of Commerce, showing that 77% of manufacturers had attempted recruitment and 71% having difficulty in doing so, with skilled manual labour being the main area of difficulty.

The Heart of the Southwest LEP (HoSW, 2018) also examined the future needs of organisations, showing that the demand for advanced and general digital skills will increase.

A Shortage of Digital Engineers

According to Laura Griffiths, (2018) it is rare to find digital engineers. People either really know about manufacturing or, come from computer science backgrounds and know quite a lot about maths or programming or artificial intelligence. There is a lot of potential to bring people from the outside into manufacturing and attract them into digital manufacturing (Griffiths, 2018). The Industrial Digitisation Review (2017) found that businesses faced a skills shortage, particularly in digital engineering.

This is a common problem for other industries, and there have been many attempts to address these issues by producing new courses (hence the wide range of "flavours" of computer science degree).

The Industrial Digitisation Review (2017) cited the lack of coherence and coordination in the digital skills education as being a barrier to recruiting people with the right skills. It stated that the skills system suffers from extreme fragmentation and duplication and the level of systematic engagement of industry with skills and education fall significantly short of the dynamism required for a future digitally enabled world.

The review recommended that:
"Industry should work with government and higher education institutions to create a virtual Institute of Digital Engineering which would showcase and spread best practice in learning and development, focused on both the workforce of the future, and the upskilling of the existing workforce."

The 2017 Made Smarter Review stated that:
"A lack of digital skills has been identified as the most significant barrier preventing the UK achieving its goal of being a world leader in IDT. The immediate priority is thus for industry and government to work together to increase the level of IDT skills in the existing workforce."

This will be achieved through:
- Increasing investment and uptake in skills acquisition.
- Better identifying future skills requirements.
- Improving the provision of and access to quality training to support those future skills.
- Creating an agile skills development system able to respond to rapidly changing market needs.
- Creating a culture of lifelong learning and more visible career pathways for adults.

They also propose:
"A central coordinating body for industrial digital skills, in the form of a Made Smarter Skills Strategy and Implementation Group (SSIG), to promote good practice and innovation in skills development through an open partnership of employers and their representatives (e.g. professional institutions), universities, private training providers, experts in online learning delivery, and professional bodies. The SSIG would also work in collaboration with regional and local agencies (e.g. Local Enterprise Partnerships, Skills Development Scotland, etc.)" (Maier, 2017)

The Importance of Data Analytics
According to research carried out by TechUK, big data and data analytics represented the largest proportion of UK digital vacancies in the short to medium term, with 62% of companies requiring more big data capability (TechUK, 2014; TechUK 2016). Data Analytics comes up in a number of reports on the skills gap (IBSA, 2016; HoSW, 2018), and should still be seen as one of the advanced digital skills that is in demand and cuts across the advanced manufacturing sector as well as many others.

Digital Skills Gaps By Manufacturing Sector

A selection of industry sectors are presented here with some evidence as to where the specific skills gaps lie. Each sector is likely to need a more detailed analysis than is presented here, and this provides a starting point for each based on currently available data. There are a number of reviews of education and training in a number of these sectors, and also consultancy firms provide a number of reports around digital skills. Each sector is highly specialised, and this will be a contributing factor in finding and securing a workforce with the right skills.

Digital Skills Gaps In Aerospace
Talent in the Aerospace industry is in high demand and can be very difficult to find, with businesses often competing with one another in the market to secure these skills.

Taking a more agile approach, such as the use of a contractor, could be a solution to secure the right type of talent – enabling the recruitment of a high value specialist resource to help futureproof a business, but also negating the need to hire permanent staff for shorter term projects (Caley, 2018; RAS, 2020).

Thi is an industry that is likely to be seriously affected by the COVID-19 Pandemic. Therefore some more detailed analysis of the industry and the benefits of digitalisation would be recommended.

Digital Skills Gaps In Pharmaceutical/Biotechnology
Skills shortages in a variety of computational disciplines were reported by the ABPI (2018), as identified in the Topol Review (2018).

These included:
- Genomics
- Bioinformatics and Chemoinformatics
- Clinical pharmacology
- Immunology

The review highlights that cross disciplinary collaboration is the way forward in addressing the digital skills gaps. The digital skills gap in Healthcare is the focus of another IoC report.

Digital Skills Gaps In Automotive
A significant report was produced by KPMG (2017) citing a lack of knowledge and digital capability, with pockets of digital expertise not sufficiently integrated nor working together. The digital skills gap in Automotive is the focus of another IoC report.

Digital Skills Gaps In Military And Defence
In a report to the House of Commons Public Accounts Committee, it was noted that the Ministry of Defence is assessing the changing demands of modern warfare and the need to enhance its skills in technical and digital areas, including cyber specialists (HoC 2018).

Digital Skills Gaps in Construction and Infrastructure
In a report by Balfour Beatty (2019), it was noted that automation and digitisation will continue to disrupt the construction labour market, seeing new roles emerge and some disappear. They consider that the pace of change is beginning to accelerate and there will be a need to fill high-skill roles that will result from automation. They see these high skill roles as taking over from low skill roles, and that digital skills will play an increasingly important role (Balfour Beatty, 2019).

Digital Skills Gaps in Food and Drink
IDG, a charity specialising in education and training for the food industry report (IDG, 2017) that many companies recognise the increasing role of technology and the requirement for an appropriately skilled workforce. They state that the meaning of the term 'digital skills' and the actual requirements of the industry varies widely from one business to another. However, only 7% are reported as using more sophisticated skills such as coding, programming or website building, and that there is a need for a range of digital skills in the way they work and in the interaction with customers.

Engineering is the hardest technical area for the food and grocery industry to recruit and the report points to the failure of science, technology, engineering and mathematics (STEM) to attract and retain increasing numbers of young people, and in particular women.

The food and drink sector has many regulations and, in particular, health and safety which requires traceability. The digitalisation of traceability is really important (see https://www.food.gov.uk/sites/default/files/media/document/10850-fsa-guidance-on-food-rec a lls_accessible-master-ln.pdf)

It is also a high volume sector with a significant amount of automation, so digital skills in demand will match those of other manufacturing sectors. This may have a knock on effect on the entire supply chain of the hospitality sector.

Note: As pubs, restaurants and hotels start to open up we are seeing the adoption of digital technologies, on-line booking systems to reserve your table, ordering of food and drinks will be via apps, cashless payments, with information being recorded for track and trace purposes. Whilst the focus here is on advanced manufacturing, as consumers are exposed to more digitisation it is likely to have an impact on the entire supply chain.

Digital Skills Gaps in Oil and Gas

The Industrial Internet of Things is considered set to revolutionise the industry and oil and gas companies are collecting more digital data, helping to improve worker safety, monitor reservoir behaviour, plan ahead for smoother digs, maintain hardware etc. Energy companies, therefore, need more software engineers and data scientists (Airswift, 2019).

There is some discussion around Automation but the feeling is that this is not considered a major area (Mills, 2018). However, there is a reported lack of skilled IT Staff , which is recognised as a limiting factor when adopting new technologies (Gilam, 2019).

Digital Skills Gaps In Chemicals

Shortages affecting the food industry, pharmaceutical industry and the oil and gas industries will also affect the chemical industry. The skills shortages were addressed in detail in the Northern Powerhouse Chemicals and Process Sector Science and Innovation Audit (Northern Powerhouse, 2019) It points to a number of skills needs:

- Core science skills which lay the foundations for new technology driven skills
- Industrial Digitisation and Big Data Skills (Informatics, computational science and statistics)
- Machine Learning and AI
- Greater regulatory and intellectual property awareness and better problem solving skills
- Leadership, team working and commercial awareness will become ever more important

The report also states that there is a particular difficulty in finding people with the right mix of skills – those who combine scientific or healthcare knowledge with digital skills.

The spread of new technologies is dependent on people, who need to have the cross-cutting skills which enable communication and innovation. There is a greater need for collaborative working, sharing knowledge and resources across organisational and international boundaries. Knowledge transfer between experienced workers and new entrants will also be essential as significant proportions of the workforce approach retirement.

This has many of the key themes, relating to upskilling an existing workforce, flexibility and adaptability of a workforce, and a mix of industry experience alongside the relevant hard digital skills.

Digital Skills Gaps In Energy

In an article by the Norfolk Chambers of Commerce, (Thorp, nd) it is stated that the energy sector is forecast to grow by 15.5% by 2022. They suggest that in the energy sector the problems are due to increased demand for skill workers, an aging workforce, lack of new entrants into employment and a changing sector.

Whilst this does not immediately suggest that energy has a digital skills shortage, there are a number of reports around the digitalisation of the industry (DNV-GL, 2019), and this is where a combination of digital skills and sector skills will be needed. In their report DNV-GL (2019) state that data science is stated as being an in demand job role, whilst relatively few businesses surveyed actually employ data scientists.

The STEM Skills Gap

Conbrio (2019) reported that, at the time of writing, there were over 600 organisations running STEM initiatives. It is unclear if they have had the desired impact of increasing uptake of STEM subjects among young people. An evaluation of these initiatives would be very useful here, and it would also be interesting to discover more about how much digital skills feature in STEM initiatives.

6. Supply of Digital Skills to the Sector

Higher Education Approaches To Digital Skills Education

This is a survey of university courses offered across the UK HE sector. A more detailed review may be useful and the data would benefit from regular updates to keep it current. The tables relating to this data are in Appendix B.

Undergraduate Courses
As of July 2019, 191 UK universities on WhatUni.com offer 2372 courses under the title "Computing and IT".

Many undergraduate courses have 'traditional' titles such as "Computer Science" or "Computing", but the majority have more than one flavour of degree, for example: Computing for Business, Business Information Technology, Digital and Technology Solutions Professional (Cyber Security) (Data Analysis) (Network Engineer) (Software Engineering)

The computer sciences degrees refer to some of the in demand digital skills relating to Advanced Manufacturing, but are not specific to the sector, and are unlikely to have much content specifically relating to manufacturing or engineering.

Postgraduate Degrees
The titles of postgraduate degrees (Table B2) are likely to be less informative than undergraduate, as many offerings allow individual students considerable leeway in their area of study. However post-graduate programmes offer an opportunity for specialist study which cannot easily be matched by undergraduate programmes. Additionally, postgraduate MSc programmes tend to be 1 year, full-time programmes and therefore can generate graduates with specific skills more quickly. There are some programmes (such as those at Manchester Metropolitan University) that offer a two year MSc, where year 2 is spent on an industrial placement (MMU, 2020).

The data presented in Table B1 shows that there are currently over 1500 courses that can be considered relevant to Advanced Manufacturing across the 191 universities sampled.

Research and Innovation
There are now 16 EPSRC Centres for Innovative Manufacturing (CIMs) spread across the UK. These are tasked with enabling the commercial development of university manufacturing research. Some are focused on future products such as composites, food and pharmaceuticals and some focus on production technologies and how they scale up, such as additive manufacturing and automation (EPSRC, nd).

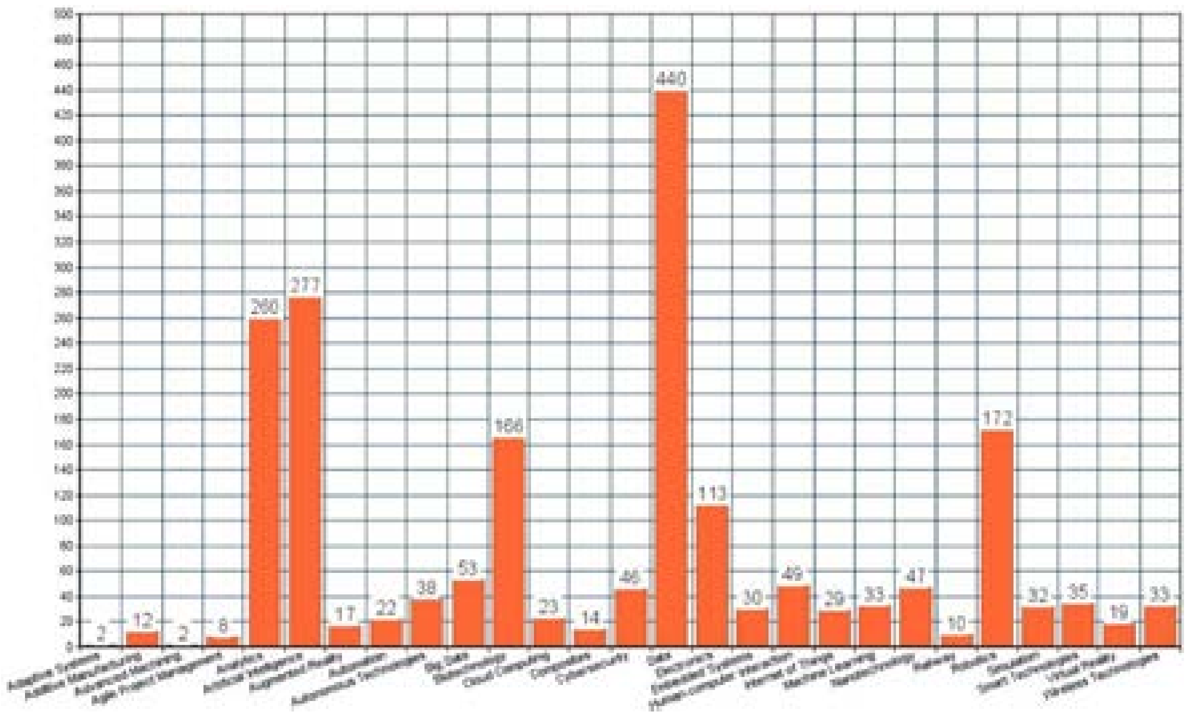


Figure 6.1 A mapping of courses to technology trends

Whilst research and innovation initiatives are not designed to address the current digital skills gaps, they are something that can be used to communicate the need for future skills, and the exciting innovations that will cause those skills to be in demand. So whilst we do not consider them directly addressing the skills gap, the Centres for Innovative Manufacturing can usefully support the industries they serve by helping to attract the right people into them.

Whilst the focus of these centres is around research, and attracting the funding required to continue that research, the promotion of advanced manufacturing as a career could be seen as part of the impact of these centres.

Matching Course Provision to Trends
It is important to match offerings at all levels to current trends in the digitalisation of the manufacturing sector. Table B6 is a rough tabulation of current (2019) degree courses, using the course titles as an identifier. Many other courses may include these subject areas as part of other degrees and qualifications. The data are presented as a bar graph in Figure 6.1. It is immediately obvious that there is a mismatch between employer implementation of cloud computing, additive manufacturing, cybersecurity, Internet of Things, machine learning and other trending technologies.

Degree Apprenticeships
Any review of digital skills in advanced manufacturing has to examine the role of apprenticeships in providing those skills. There are apprenticeships at intermediate (Level 2) and advanced (Level 3) level, which may lead to higher apprenticeships (Levels 4-6) and degree apprenticeships. Here we focus on degree apprenticeships, which provide a qualification at Level 6 or Level 7, as they offer the main alternative to a traditional university education.

Table 6.1 shows the level 6 degree apprenticeship standards that were relevant to Advanced Manufacturing as of August 2019 (taken from the Institute of Apprenticeships). Of the 32 level 6 standards relevant to Advanced Manufacturing, 9 (28%) are "in development". This means that even if these standards come into play in 2020, individuals will not graduate until 2024 at the earliest. There is a similar proportion for level 7 Degree Apprenticeships (Table 6.2). However, since there is a significant proportion of workplace learning involved, they will start to be useful far earlier than that.

A number of apprentices are taken from existing staff, and some of these will be gaining a qualification for work they are already doing. This means that they cannot count as new skilled employees. It would be interesting to understand the mix of existing employees vs new employees, and of the existing employees how many are considered to be upskilling to take on a new role.

Of the 19 level 7-8 standards relevant to Advanced Manufacturing, 9 (47%) are "in development." This means that even if these standards come into play in 2020, individuals will not graduate until 2022 at the earliest.

Similarly, of the 32 level 6 standards relevant to Advanced Manufacturing, 9 (28%) are "in development." This means that even if these standards come into play in 2020, individuals will not graduate until 2024 at the earliest.

In 2017, Universities UK (UUK, 2017) gave some advice to universities and Government around Degree Apprenticeships. They stated that universities should ensure that they work closely with employers, using their existing networks and creating new ones, to promote and provide relevant degree apprenticeships. It was also suggested that universities should work more closely with Further Education Colleges in the delivery and administration of Degree Apprenticeships. It also recognised the role the Government needs to play in the promotion of degree apprenticeships, and informing careers advisors. This reinforces the multi agency approach that is required to address the skills gap, and apprenticeships do offer the essential workplace learning element that is commonly required for a graduate to demonstrate employability. However, as stated in the HEFCW (2019) policy document, there needs to be meaningful partnerships, real opportunities and sustainable funding for apprenticeships.

Table 6.1 - Level 6 Degree Apprenticeship Standards

Subject	
Aerospace Engineer (degree)	September 2015
Aerospace software development engineer (degree)	September 2015
Building services design engineer (degree)	October 2017
Civil Engineer (degree)	October 2017
Construction Design management (degree)	In development
Control/technical support engineer (degree)	November 2014
Cyber security technical professional (integrated degree)	September 2018
Digital and technology solutions professional (integrated degree)	March 2015
Digital and technology solutions specialist (integrated degree)	August 2018
Digital user experience (UX) professional (integrated degree)	In development
Electrical/electronic technical support engineer (degree)	November 2014
Electro-mechanical design and development engineer (degree)	In development

Table 6.1 - Continued

Subject	
Embedded electronic systems design and development engineer (degree)	June 2016
Engineering geology degree apprenticeship	In development
Food and Drink advanced engineer (degree)	February 2018
Food industry technical professional (degree)	June 2017
Improvement leader	January 2019
Manufacturing engineer (degree)	November 2014
Manufacturing manager (degree)	February 2019
Non-destructive testing engineer (degree)	November 2017
Nuclear reactor desk engineer	In development
Nuclear scientist and nuclear engineer (degree)	September 2015
Packaging professional (degree)	June 2018
Product design and development engineer (degree)	November 2014
Project controls professional	In development
Project manager(degree)	June 2018
Quality leader	In development
Rail and rail systems senior engineer (degree)	July 2018
Science industry process/plant engineer (degree)	February 2018
Space engineer (degree)	In development
Supply chain leadership professional (degree)	December 2018
Tool process design engineer	In development

Table 6.2 - Degree Apprenticeship Standards at Level 7

Subject	
Artificial intelligence (AI) data specialist (degree)	In development
Bioinformatics scientist	January 2019
Digital and technology solutions specialist (integrated degree)	August 2018
Electronic systems principal engineer	July 2019
Engineering Process Industries Professional	In development
Geotechnical engineer	In development
Light water reactor scientist and engineer	In development
Materials process engineer (degree)	March 2019
Post graduate engineer	March 2017
Power and Propulsion Engineer	In development
Power engineer (degree)	February 2017
Process automation engineer (degree)	October 2017
Rail & rail systems principal engineer (degree)	June 2018
Senior leader	February 2018
Sustainable Business Specialist	In development
Systems engineer (degree)	September 2015
Systems thinking practitioner	In development
Technical specialist in nuclear engineering, science or technology	In development
Through life engineering services specialist	In development

Institutional/Partnership Approaches To Digital Skills

Whilst the Institutes of Technology appear to be partially outside the scope of the IoC they will cater for levels 4 and 5 students, the proposed Newport National Technology Institute is being promoted as addressing “the gap in applied high-level teaching and learning in advanced (digital) technology. It will be a disruptive higher education institution.”

The Newport Economic Network (2019) states that "the current university model of learning isn't doing enough to provide Welsh employers with the necessary number of graduates with required hi-tech focused learning skills…the existing institutions are currently struggling to satisfy the fast-moving needs of the students or the demands of the technology centric organisations wishing to employ them ." This has been repeated in other reports.

If successful, the Newport Institute would join the Cardiff National Software Academy, the Computational Foundry (Swansea University) and the Cyber Academy (University of South Wales) in catering for the skills needs of Wales, and like the Centre for Work-Based Learning in Scotland, and the Cyber Foundry, AI Foundry and PrintCity in Greater Manchester, aim to offer different approaches to acquiring skills that challenge the traditional university model.

The type of experience they offer includes:

- Transferable Skills/Soft Skills
- Adaptive resilience
- Student input on curriculum
- On-campus work experience
- No timetable
- Individual learning paths
- Links and partnerships
- Lifelong learning

Upskilling and Experiential Learning

In September 2012, the UK Government published an overview of advanced manufacturing (Griffiths and Snape, 2012). It reported that the advanced manufacturing workforce would require more highly skilled technicians, running automated factories, than low skilled assembly and production line workers. They suggested then that the workforce should include 30% Graduates and 40% Higher Level Apprenticeships.

More recently, the Made Smarter Review of 2017 (Maier, 2017) stated that two-thirds (65%) of the workforce of 2030 has already left the education system and that, therefore, the UK cannot rely on the education system to satisfy industry's demand for digital skills in the short to medium term. The review stated that there were potentially 2 million people that would need to be upskilled or re-skilled in the workplace.

A 2019 HEFCW consultation on Degree Apprenticeships (HEFCW, 2019) found that there is an increasing demand for Level 7 Leadership and Management development, which would enable managers to understand global and technological changes.

Barriers to Upskilling

In 2018, the CBI and Universities UK suggested that whilst there were many good examples of employers working with universities to upskill staff, some employers, who did not already have relationships with universities were finding it difficult to begin that engagement. (UUK, 2018a). This suggests that there is more work to do in industry engagement, however additional concerns cited were around the length of university courses and their cost.

In 2018 Accenture Research (reported by Consultancy UK (2018)) stated that the majority of future science and engineering jobs will be augmented by intelligent systems, and that many of the skills for the future workplace are best acquired through practice and hands-on experience and experiential learning that could apply to university-delivered skills acquisition. In addition to the speeding up of experiential learning, they also believe that there should be a shift to individualised training, including complex reasoning, creativity, and socio-emotional intelligence. Targeted intervention and new funding models will also improve access for more vulnerable employees (those in low skilled roles, older employees, or those with less access to training).

There are, therefore, a number of barriers to upskilling and lifelong learning which need to be overcome. Examples of these include:

- A lack of motivation amongst employees to acquire new skills (particularly vulnerable groups).
- A lack of inspirational leadership amongst employers and/or training providers
- A shortage of appropriate accessible resources/expertise (due to location, timing, transport or facilities etc.).
- The costs associated with university courses
- The length and relevance of university courses
- The lack of flexibility in the delivery of university courses

There should be consideration of the areas of expertise that are strategically important for each region, based on real employer demand, and supporting a wider strategy of anchoring companies and creating more graduate jobs in the region.

Private Approaches To Digital Skills

There are a number of commercial training companies that offer programmes aimed at filling skills gaps. These do not offer degree level programmes, and are often not providing only digital skills. However, they are likely to be more agile, and appear more cost effective in the short term than university courses.

An example is Experis Academy, which works with clients to identify specific skills shortages and then groups them with an 'ecosystem' of companies within a supply chain, companies with shared interdependencies, industry groups, or a consortium. Once skills gaps and future skills requirements have been defined, Experis works with the ecosystem partners to create highly bespoke training programmes that address specific skills shortages (Manpower, 2020).

Buffalo State University, and many others are offering courses on platforms like Coursera. These may be a range of tasters and university level courses, although some of these may not be as agile as shorter training programmes, they will certainly offer more flexibility in delivery.

Organisations like Northcoders believe that they can have the agility to change curriculum in a way that universities do not, having the ability to change their curriculum in a matter of days. Northcoders also state that they can help make coding more accessible than universities as their coding bootcamp runs for just three months. Whilst the agility of such programmes is undeniable, there are issues around certification that might need to be explored further.

Skills Delivery Models

According to a recent Digital Transformation report by accountants and financial advisory firm BDO, (2019):

- 84% of businesses surveyed say the Government must do more to deliver skills for manufacturing digitalisation,
- 78% stated that the education system is failing to deliver the right STEM skills for the future.

The solutions to the digital skills gap is a collaboration between government, education providers and employers, all of which have a different perspective on what the skills gap is, and how it should be closed. Some of the discussion around solutions is presented here.

Adaptive Capacity
The IBSA (2018) report warns against "occupational obsolescence" and takes the view that vocational education should be targeting tomorrow's jobs, but, rather than focussing on highly specific job roles, should provide vocational streams for a number of closely related occupations. They refer to this as adaptive capacity. However this would need to be supported, possibly by workplace learning of some kind, in order to ensure that the learners do become employable, but remain adaptive.

This kind of vocational education is already present in the UK at level 3, but we should be considering a similar model for higher education. Perhaps with the model of a generalist BSc and specialist MSc.

Agility and Flexibility
An Open University press release states that "Organisations need an agile workforce that can embrace change and meet new challenges." (Wilhelm, 2017). Advanced manufacturing needs to be agile to meet the demands of modern markets. We practice agile software development, and agile project management to ensure we are meeting the requirements of our customers. It is probably time for the HE sector to become more agile in the way it develops its courses.

A Universities UK report states that "educators and employers need to collaborate more closely, and develop new and innovative partnerships and flexible learning approaches." (UUK, 2017)

There is also discussion around the amount of knowledge that becomes out of date, although this tends to me more true of skills rather than knowledge. If university courses are to remain relevant then it is more likely that the skills components of their programmes need to be adapted rather than the underpinning knowledge. Therefore university programmes do need to be able to provide skills/competence elements that are either tailored to a specific job role, or provide a specific skill set, which it is recognised will need to change during the career of the learner.

The Heart of the South West LEP (HoSW, 2018) recognised that the needs of SMEs differ from those of larger organisations. For large organisations a broad skill-set was needed, with outsourcing of more expert support when needed. For SMEs there seems to be the same need, but often they need support to help them understand what they do not know.

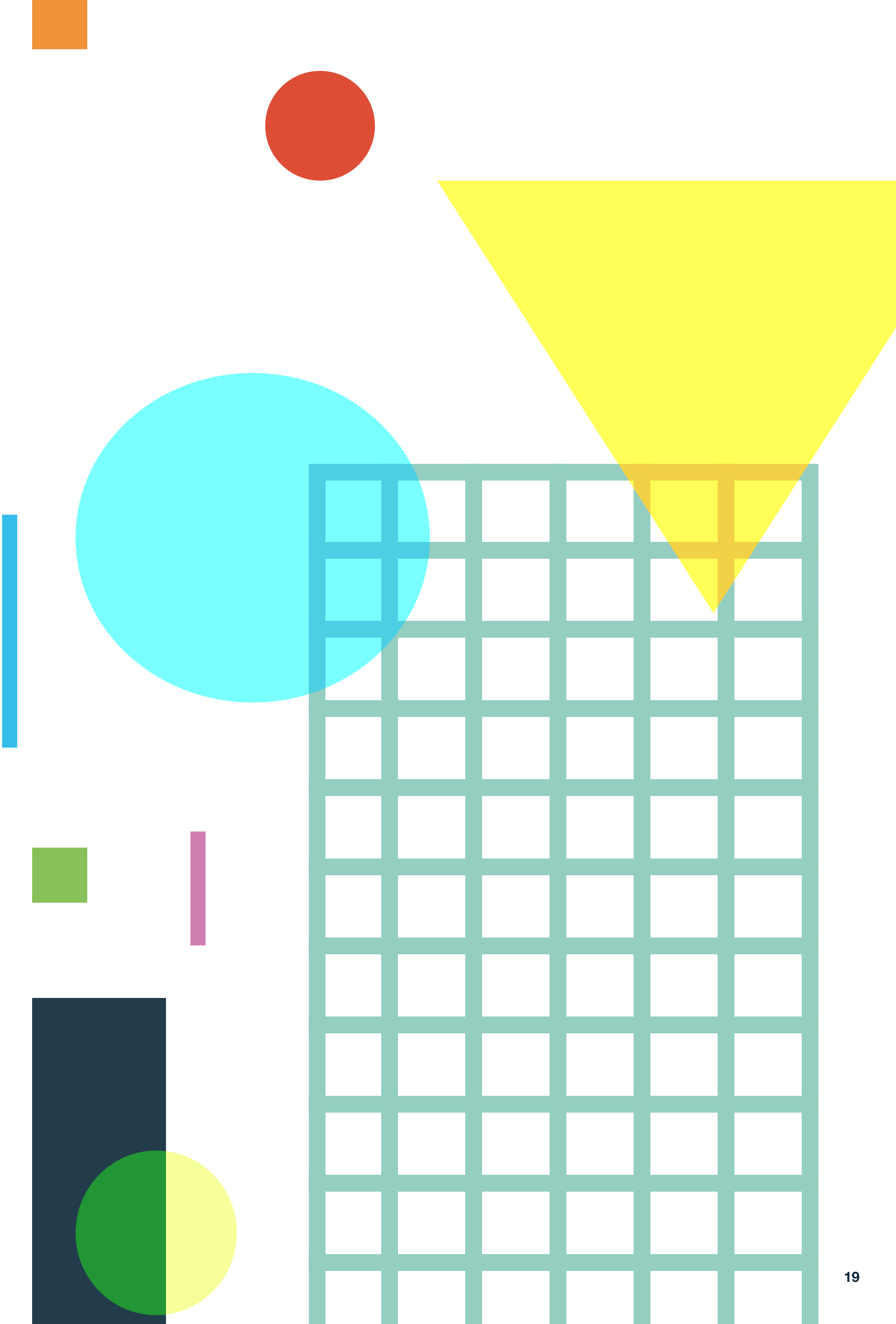
In an interview for The Engineer (2019) Brian Holliday, Managing Director for Digital Industries at Siemens, suggested that it was most important to have employees who were agile, digitally competent, creative, collaborative and practical. These are not dependent on advanced STEM qualifications, although they can certainly be developed as part of such a programme.

Where do employers go for training?
According to the heart of the Southwest Digital Skills review, only 12% of digital training is carried out at Universities with an additional 12% at Colleges of Further Education. The need for highly up to date skills was given as the main reason for choosing bespoke training, and it was felt that the uniqueness of training requirements were not being satisfied in educational establishments.

The survey also showed that the main barrier to training was uncertainty as to whether the course actually met the need. There are lessons to be learnt from Deloitte (Pelster, et al. 2017). They suggest that the LMS is getting old, and that more modern tools that provide curated content, video and mobile learning, micro-learning, and new ways to integrate external MOOCs.

Many SMEs are applying for funding for ERP systems just simply to get a handle around what is happening on their shop floor, many still use paper based systems and by the time they are collated and entered into a spreadsheet they are obsolete. They also don't know where to start or what to digitise first. Do you go for full automation, or install some sensors that give you key data that allows effective decisions to be taken that improves efficiencies. So mechanical engineering students really need to have software skills, understand how connectivity works, and how to analyse data.

There is a useful survey at d rl-tool.org that companies can undertake to see how digital they really are. It then helps them understand what they need to do to get to the next level.



7. Conclusions and Recommendations

The purpose of this report is to analyse the Digital Skills Gaps in the Advanced Manufacturing Industries, in order to understand how the Institute of Coding, and Higher Education Institutions delivering computer science, can help to close these skills gaps by providing up to date and relevant HE programmes at Level 6 and Level 7.

It is clear from the research carried out for this report that the advanced manufacturing sector is wide, with each sector requiring some specialised skills in order to keep pace with the rate of technological change. We identify 9 different sectors that can be considered Advanced Manufacturing, but this is not an exhaustive list and each sector may itself be drilled down further. We have also identified 46 technology trends that are considered part of Advanced manufacturing. All of these have been selected because they require some level of digital skills, but some are clearly more distant from computer science than others. This suggests that there is a need for employees with some core, advanced digital skills which will also need to be augmented with additional sector related skills.

A Complex Sector

Given the complexity of the sector, and the regional nature of employers, it will be necessary for local HEIs and training providers to maintain closer links with their local employer needs. Reports suggest that there is clearly a need to do more, and university outreach departments and BDMs need to ensure they are making full use of local Chambers of Commerce, Local Enterprise Partnerships and local councils in order to meet this need.

Conversely there is also a need for industry to engage more with universities and training providers to ensure that their needs are being heard.

The Required Volume of Skilled Employees

There have been a number of previous reports examining the skills gaps, and making recommendations as to how they should be dealt with. An important aspect of the work here is in its consideration of actual numbers of graduates that can be produced and the timescale over which they will begin to enter the workforce. There is a role to be played by universities in the production of graduates with the required skills, but this alone will not seriously address the skills gap, and certainly not in the short term. The numbers of skilled employees that can be produced appear impressive on their own, but when compared the current, and future shortfall, alongside a deeper examination of the skills that they need, it is clear that there is much more work to do. The Institute of Coding is in the unique position of having partner HEIs across every region in England, and it should consider ways in which programmes developed by one partner can be shared more readily with others, ensuring that larger numbers of skilled graduates can be produced.

Reducing Costs, but not Quality

Training employees has costs for all stakeholders, and in order to achieve the required volume of skilled employees, it will be important to reduce these costs, but not at the expense of quality.

Models of Delivery

Existing models of delivery may not be sufficient to produce employees with the required skills at the right pace, and educators and trainers need to go beyond the delivery of skills and ensure that graduates and other learners can make up a flexible workforce that has the right attitude, and aptitude to learn new skills as and when they are required. This need for ‘employability skills’ has long been cited by both universities and employers, although there is sometimes a difference as to what is meant by employability skills. Developing graduates with core, advanced digital skills, plus employability skills may be a good fit for Computer science undergraduate programmes. However, taught masters programmes may be the better vehicle for delivering sector specific digital skills.

Agility and Flexibility

There is an issue regarding the time it takes to develop, and/or update traditional university courses, and the modes of delivery they often take. Whilst some degree programmes are becoming more agile, (such as the Industrial Digitalisation MSc at Manchester Metropolitan University), they are often not flexible or agile enough to meet the demands of a rapidly changing environment, and we believe that the agility of course development, and the flexibility of delivery both need to be addressed by universities.

Other models of delivery, in particular apprenticeships, are rapidly becoming comparable to full time university degree programmes in terms of numbers. These, and other workplace learning mechanisms are more able to fill the shorter term skills needs of organisations, and universities, training providers, and employers need to work together to reduce the barriers to successful experiential learning.

Recommendations

The ability for universities and employers to follow these recommendations will be determined by their size, turnover, expertise, and many other factors. These are general recommendations of good practice, that will have an effect on the skills gaps,

For Universities:

- Ensure regular communication with local Chambers of Commerce, LEPs and local councils, as well as having representation at local meetups and industry groups
- Regularly review the content of programmes against the technology trends, and provide clear, up to date, signposting of where these skills are developed to both employers and prospective students.
- Ensure the ways in which industry can talk to you are prominent and easy to find.
- Regularly review the mix of undergraduate and postgraduate programmes, and how they are meeting local industry needs, creating programmes that meet those needs through partnerships with industry.
- Review the agility of course development processes, particularly for in-demand sectors.
- Review the flexibility of delivery for both full-time programmes and workplace learning programmes.
- Ensure the right employability skills are being learnt by ensuring some industry engagement in their delivery (e.g. by involving IABs in providing live projects and industrial placements).
- Diversify the student populations so that there are larger numbers of learners.
- Carry out regular reviews of regional employers and their digital skills needs.

For Employers:

- Ensure regular communication with local Chambers of Commerce and LEPs, as well as local university BDMs.
- Offer opportunities for placements/work experience, so make use of skills as early as possible
- Use vehicles, such as KTPs to buy in more advanced skills, and work on specific projects
- Sit on university Industry Advisory Boards in order to influence the decision making and raise your profile within HEIs.
- Employ apprentices, or put forward existing employees, at any level to enhance workplace learning
- Offer flexible working for employees who want to undertake personal training and development
- Contribute to employer surveys looking at digital skills gaps.

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Appendix A - Technology Trends in Advanced Manufacturing

The following represents the digital trends set out in Conbrio (2019) that relate to advanced manufacturing. It acts partly as a glossary of terms, and partly as an indicator of the breadth of technologies used in the digitalisation of manufacturing or as drivers for the digitalisation of manufacturing. Many of these will benefit from some analysis in their own right.

Adaptive Technology:

Adaptive manufacturing includes flexible reconfiguration and technology that can adapt to different types of feedstock Self-adaptive production lines. Adaptive sensor networks. Adaptive communications. Adaptive control. Adaptive computing mimics biological systems that can adapt to new environments.
h ttps://www.liverpoollep.org/wp-content/uploads/2015/06/wpid-making-it-2020final2.pdf

Additive Manufacturing:

Building solid objects by adding material in layers using digitally-controlled machine tools. Reduces lead times, total cost. Industrial machines, automotive, aeronautical, personalised consumer products, customised production tool, medical devices. Rapid prototyping. 46 per cent of UK manufacturers use 3D printing for prototyping (Deloitte, 2019a). It is strongly recommended that further analysis be done in this area as many new courses are coming online each year.

Advanced Machining:

Utilises chemical, electrical and high energy beams. e.g. chemical machining, electrochemical machining, laser beam machining, plasma arc cutting, ultrasonic machining, abrasive jet machining.

Agile Development and Operations:

An iterative approach that produces and delivers work in short bursts. Scrum. Learn.

Artificial Intelligence (AI):

AI is the ability of machines and systems to acquire and apply knowledge and carry out intelligent behaviour. The OECD predicts that sectors likely to experience AI-based transformation include: Agriculture, Chemicals, Rubber and plastics, Shoe and textile manufacturing, Transport, Construction, Defence, Surveillance and security.
AI will also be deployed in a wide range of services, including healthcare, entertainment, marketing and finance driving the demand for knowledge workers able to develop AI or undertake tasks that complement AI (HoSW, 2019).

Augmented Reality (AR):

A composite vision of the world created by the superimposing of a virtual image onto an individual's own vision.

Automation:

The replacement or augmentation of human control of a process by a technology, usually a machine or a control system, often itself controlled by a computer.

Autonomous Technologies:

Systems that can react to information or stimuli without the intervention of humans.

Big Data Management:

Big Data are large compilations of information that can be analysed in order to reveal patterns, trends and associations.

Biotechnology:

The manufacture of chemical products using biological materials.

Blockchain:

Blockchain is a distributed database that acts as an open, shared and trusted public ledger that nobody can tamper with and everyone can inspect. Blockchain technology was originally conceived for Bitcoin, but the expected impacts of blockchain technology go beyond digital finance and may significantly affect any activity involving authenticating a transaction. Applications include financial transactions; record and verification systems and smart contracts (OECD, 2012).

Building Information Modelling (BIM):

BIM (Building Information Modelling) is an intelligent 3D model based process that gives architecture, engineering, and construction professionals the insight and tools to more efficiently plan, design, construct, and manage buildings and infrastructure.
(h ttps://www.pwc.co.uk/industries/assets/2019-annual-manufacturing-report-final-web.pdf)

Cloud Computing:

Simply put, cloud computing is the delivery of computing services—including servers, storage, databases, networking, software, analytics, and intelligence—over the Internet ("the cloud") to offer faster innovation, flexible resources, and economies of scale. You typically pay only for cloud services you use, helping you lower your operating costs, run your infrastructure more efficiently, and scale as your business needs change. At present the cloud is used by over 80 per cent of UK companies.

Cobots:

Collaborative robots that can work alongside humans in a safe way and that can assist humans in their tasks, e.g. supporting the lifting of heavy items, or electronic assembly. Typically robots are put inside cages to protect any workers on the shop floor, with industry. 4 there is a need to get them out of the cages.

Collaboration

Connectivity

Composites

The joining of two materials to produce one with superior mechanical properties.

Data Analytics/Data Mining/Big Data Management:
Data analytics is the science of analysing raw data in order to make conclusions about that information. Many of the techniques and processes of data analytics have been automated into mechanical processes and algorithms that work over raw data for human consumption. 47 per cent of UK manufacturers plan to embed data analytics.
Data mining is a process used by companies to turn raw data into useful information. By using software to look for patterns in large batches of data, businesses can learn more about their customers to develop more effective marketing strategies, increase sales and decrease costs.
Big Data management tends to refer to the overarching management and governance of large data sets.

Design Thinking:

Design Thinking is a design methodology that provides a solution-based approach to solving problems.

Digital Platforms:

Digital platforms are online businesses that facilitate commercial interactions between at least two different groups—with one typically being suppliers and the other consumers.

Digital Railway:

Digital Railway is the industry's improved plan to tackle the UK's capacity crunch by accelerating the digital modernisation of the railway (https://digitalrailway.co.uk/) .

Digital Twins:

Integration of AI, machine learning, predictive analytics and sensor telemetry to create digital clones of live and historical performance of physical machines and idealised digital simulation models that evolve based on data collected from real-world instances (https://www.networkworld.com/article/3280225/what-is-digital-twin-technology-and-why-it-matters.html) .

Embedded Intelligence:

Embedded Intelligence requires the use of sensors, communications and processing that are embedded into the product, process or service in order to meet specific objectives. As such, the embodiment of EI depends on a multidisciplinary approach for successful implementation. Combines IoT, blockchain and AI.

Extreme Personalisation:

Extreme personalization, sometimes referred to as marketing to a customer segment of one, is the holy grail of the multi-channel world. To get to extreme personalization, marketers must have what they need to reach out directly to a real individual, rather than a general marketing persona. The underlying technology that powers extreme personalization is an omnichannel commerce platform (h ttps://www.elasticpath.com/sites/default/files/Extreme%20 Personalization.pdf) .

Generative Design:

Generative design replicates the natural world's evolutionary approach with cloud computing to provide thousands of solutions to one engineering problem (h ttps://www.newequipment.com/research-and-development/article/22059780/what-generati v e-design-is-and-why-its-the-future-of-manufacturing). Generative design is a design exploration process. Designers or engineers input design goals into the generative design software, along with parameters such as performance or spatial requirements, materials, manufacturing methods, and cost constraints.

Human-machine Interaction/Interface:

A Human-Machine Interface (HMI) is a user interface or dashboard that connects a person to a machine, system, or device.

Industrial Cybersecurity Management:

The protection of industrial assets from cyber threats.

Industrial UI/UX Design:

UI refers to user interface design, while UX covers user experience design.

Intelligent Enterprise Resource Planning (ERP):

Applications that use machine learning and advanced analytics built on a large, curated data set to forecast, track, learn, route, analyse, predict, report, and manage these resources and business processes (IDC). Automation of large-scale processes. ERP and CRM software used by 47 per cent of UK manufacturers.

Intelligent Manufacturing:

Intelligent manufacturing takes advantage of advanced information and manufacturing technologies to achieve flexible, smart, and reconfigurable manufacturing processes in order to address a dynamic and global market.

Internet of Things:

The IoT comprises devices and objects whose state can be altered via the Internet (or in local networks), with or without the active involvement of individuals. While the IoT has many implications for all aspects and sectors of the economy, the largest impacts are expected in healthcare, manufacturing, network industries and government [62].

Industrial Internet of Things

IoT applied to an industrial/manufacturing setting, where it must deal with specific problems of robustness, security and noise etc.

IT/OT Convergence:

The convergence of IT systems (data, information, information management, and communications) with operational technology (the safe operation and control of physical devices and processes).

Machine Learning:

Machine learning is an application of artificial intelligence (AI) that provides systems the ability to automatically learn and improve from experience without being explicitly programmed.

Nanotechnology:

The manipulation of materials at sub-atomic level to create new materials.

Plastic electronics:

Electronics created using semi-conducting plastic polymers.

Remote management and supervision

Robotics:

About 20 per cent of UK manufacturers have already implemented collaborative or autonomous robots. A further 29 per cent plan to embed robots.

Sensors

Silicon Electronics:

The creation of electronic circuits built on a single layer of single-crystal silicon.

Simulation/Modelling

Smart Device Deployment:

Software as a Service (XaaS or SaaS):
Software centrally hosted by a vendor and licenced to users/subscribers.

Speed/Efficiency

User-Facing AI:

The automation of user- or customer-facing tasks using AI.

Virtual Reality (VR):

The use of computer technology to create a simulated environment.

Wearable Technologies:

Wearable technology is a category of electronic devices that can be worn as accessories, embedded in clothing, implanted in the user's body, or even tattooed on the skin. The devices are hands-free gadgets with practical uses, powered by microprocessors and enhanced with the ability to send and receive data via the Internet.

Wireless Technologies/5G

Appendix B - Higher Education Approaches to Digital Skills

Table B1: Undergraduate Courses Relevant To Advanced Manufacturing

Course title	Number Of Courses	Number of universities
Advanced Manufacturing:	2	2
Artificial Intelligence:	171	48
Computer aided engineering:	10	3
Computer Cybernetics:	87	27
Computer Systems:	281	85
Computer Science with Intelligent Systems	1	1
Human-Computer Interface:	22	11
Cybersecurity (“Internet security”):	111	55
Systems Analysis and Design:	54	28
Internet of Things:	5	2
Electronic Engineering:	627	98
Engineering Technology:	63	33
Production Engineering:	5	2
Manufacturing:	64	24
Industrial Design:	17	11
Robotics:	78	25
Computer Forensics:	48	21
Total courses	**1646**	

Table B2: Graduate Courses Relevant To Advanced Manufacturing

Course title	Number Of Courses	Number of universities
Advanced Manufacturing:	10	7
Manufacturing Engineering:	21	13
Manufacturing Technology:	8	7
Process Engineering:	10	6
Production Engineering:	5	5
Industrial Design, Research and Development:	187	49
Human-Computer Interface:	22	11
Computer Forensics:	9	9
Computer Security Systems:	83	53
Computer Systems:	128	59
Information Management:	349	94
Information Systems:	599	119
Internet Systems:	101	65
Manufacturing:	67	33
Network Systems Management:	109	62
Network Systems Management	10	7
Software Development:	94	52
Systems	166	76
Total degrees	**1978**	

Appendix B - Higher Education Approaches to Digital Skills

Table B3: Examples Of Postgraduate Degrees Relevant To Advanced Manufacturing

Course title	University	Degree
Digital Manufacturing	University of Strathclyde	MSc
Advanced Manufacturing Technology	University of Portsmouth	MSc
Advanced Manufacturing Technology & Systems Management	University of Manchester:	MSc
Advanced Manufacturing Systems	Brunel University	MSc
Advanced Manufacturing Engineering and Management	Loughborough University	MSc
Advanced Manufacturing Technology	Northumbria University	MSc
Advanced Manufacturing Systems and Technology	Liverpool University:	MSc
Advanced Product Design Engineering & Manufacturing	Kingston University	MSc
Advanced Manufacturing Technologies	University of Sheffield	MSc (Res)
Additive Manufacturing and Advanced Manufacturing Technologies	University of Sheffield	MSc (Res)
Industrial Systems, Manufacture and Management	University of Cambridge Institute for Manufacturing:	MPhil
Advanced Materials and Additive Manufacturing	University of Derby	MSc
Advanced Technology Management (Manufacturing)	University of Wolverhampton	MSc
Industrial DIgitalisation	Manchester Metropolitan University	MSc
Production Engineering and Operations Management MSc	Coventry University	MSc

Table B4: HE Research Groups and Institutions Relevant to Advanced Engineering

University	Institution/group	Location
University of Nottingham	Advanced Manufacturing Technology Research Group	
University of Nottingham	Institute for Advanced Manufacturing	
University of Coventry	Institute for Advanced Manufacturing and Engineering (AME)[1]	
University of Cardiff	Engineering, Mechanics, Materials and Advanced Manufacturing	
University of Sheffield	Advanced Manufacturing Research Centre (AMRC)	Sheffield (Advanced Manufacturing Park)
University of Sheffield	Centre for Advanced Additive Manufacturing	Sheffield
University of Sheffield University of Manchester	Nuclear Advanced Manufacturing Research Centre (Nuclear AMRC)	Sheffield (Advanced Manufacturing Park)
University of Birmingham	Advanced Manufacturing Technology Centre	
University of Strathclyde	Advanced Forming Research Centre (AFRC)	Renfrew
University of Nottingham University of Birmingham Loughborough University	The Manufacturing Technology Centre (MTC)	Coventry
University of Bristol	National Composites Centre (NCC)	Bristol & Bath Science Park

[1] In partnership with Unipart Manufacturing Group

Table B5: EPSRC[1] Centres For Innovative Manufacturing

EPSRC centre	Academic partners	Location
Centre for Innovative Manufacturing in Composites	University of Nottingham University of Bristol Cranfield University University of Manchester	University of Nottingham
Centre for Innovative Manufacturing in Industrial Sustainability	University of Cambridge Cranfield University University of Surrey University of Liverpool University of Manchester London College of Fashion Royal College of Art Brunel University Cardiff University University of Strathclyde De Montfort University	University of Cambridge
EPSRC Centre for Innovative Manufacturing in Emergent Macromolecular Therapies	University College London Imperial College London	University College London
EPSRC Centre for Innovative Manufacturing in Medical Devices	University of Leeds Newcastle University University of Nottingham University of Sheffield University of Bradford	University of Leeds
Centre for Innovative Manufacturing in Photonics	University of Southampton	University of Southampton
Centre for Innovative Manufacturing in Large-Area Electronics	University of Cambridge Imperial College London University of Manchester Swansea University	University of Cambridge
Centre for Innovative Manufacturing in Liquid Metal Engineering	Brunel University University of Birmingham University of Oxford.	Brunel University
Centre for Innovative Manufacturing in Intelligent Automation	Loughborough University Cranfield University	Loughborough University
Centre for Innovative Manufacturing in Additive Manufacturing	University of Nottingham Loughborough University	University of Nottingham
Centre for Innovative Manufacturing in Advanced Metrology	University of Huddersfield	University of Huddersfield
Centre for Innovative Manufacturing in Food	University of Nottingham University of Birmingham Loughborough University	University of Nottingham
Centre for Innovative Manufacturing in Continuous Manufacturing and Crystallisation	University of Strathclyde University of Bath University of Cambridge University of Edinburgh University of Glasgow Heriot-Watt University Loughborough University	University of Strathclyde

Appendix B - Higher Education Approaches to Digital Skills

Table B5: EPSRC[1] Centres For Innovative Manufacturing

EPSRC centre	Academic partners	Location
Centre for Innovative Manufacturing in Laser-based Production Processes	Heriot-Watt University University of Cambridge Cranfield University University of Liverpool University of Manchester	Heriot-Watt University
Centre for Innovative Manufacturing in Regenerative Medicine	Loughborough University University of Nottingham Keele University	Loughborough University
Centre for Innovative Manufacturing in Through-life Engineering Services	Cranfield University Durham University	Cranfield University
Centre for Innovative Manufacturing in Ultra Precision	Cranfield University University of Cambridge National Physical Laboratory	Cranfield University

[1] The Engineering and Physical Sciences Research Council

Table B6: University Courses Related To Trends In Digital Technologies

	Undergraduate		Postgraduate		
Subject	No of universities	No of degrees	No of universities	No of degrees	"Totals"
Adaptive systems			1	1	2
Additive Manufacturing			6	6	12
Advanced machining	1	1			2
Agile project management	1	1	3	3	8
Analytics	25	51	63	121	260
Artificial Intelligence	49	171	23	34	277
Augmented Reality (AR)	4	8	2	3	17
Automation	4	6	6	6	22
Autonomous technologies	3	10	10	15	38
Big Data	1	3	21	28	53
Biotechnology	19	33	40	74	166
Cloud computing	3	4	7	9	23
Composites	1	2	4	7	14
Cybersecurity	7	17	9	13	46
Data	38	73	95	234	440
Electronics	17	50	14	32	113
Embedded Systems	2	5	9	14	30
Human-computer interface/interaction	11	22	8	8	49
Internet of Things	2	5	9	13	29
Machine learning	1	1	11	20	33
Nanotechnology	3	12	10	22	47
Railway	1	1	3	5	10
Robotics	25	78	25	44	172
Simulation	1	1	14	16	32
Smart technologies	2	3	13	17	35
Virtual Reality	5	6	4	4	19
Wireless technologies	1	1	13	18	33

Appendix B - Higher Education Approaches to Digital Skills

Table B7: Level 7-8 Apprenticeship Standards Relevant To Advanced Manufacturing[1]

Subject	xxx
Artificial intelligence (AI) data specialist (degree)	In development
Bioinformatics scientist	January 2019
Digital and technology solutions specialist (integrated degree)	August 2018
Electronic systems principal engineer	July 2019
Engineering Process Industries Professional	In development
Geotechnical engineer	In development
Light water reactor scientist and engineer	In development
Materials process engineer (degree)	March 2019
Post graduate engineer	March 2017
Power and Propulsion Engineer	In development
Power engineer (degree)	February 2017
Process automation engineer (degree)	October 2017
Rail & rail systems principal engineer (degree)	June 2018
Senior leader	February 2018
Sustainable Business Specialist	In development
Systems engineer (degree)	September 2015
Systems thinking practitioner	In development
Technical specialist in nuclear engineering, science or technology	In development
Through life engineering services specialist	In development

[1] Data from Institute for Apprenticeships and Technical Education

Table B8: Level 6 Apprenticeship Standards Relevant To Advanced Manufacturing[1]

Subject	xxx
Aerospace Engineer (degree)	September 2015
Aerospace software development engineer (degree)	September 2015
Building services design engineer (degree)	October 2017
Civil Engineer (degree)	October 2017
Construction Design management (degree)	In development
Control/technical support engineer (degree)	November 2014
Cyber security technical professional (integrated degree)	September 2018
Digital and technology solutions professional (integrated degree)	March 2015
Digital and technology solutions specialist (integrated degree)	August 2018
Digital user experience (UX) professional (integrated degree)	In development
Electrical/electronic technical support engineer (degree)	November 2014
Electro-mechanical design and development engineer (degree)	In development
Embedded electronic systems design and development engineer (degree)	June 2016
Engineering geology degree apprenticeship	In development
Food and Drink advanced engineer (degree)	February 2018
Food industry technical professional (degree)	June 2017
Improvement leader	January 2019
Manufacturing engineer (degree)	November 2014
Manufacturing manager (degree)	February 2019
Non-destructive testing engineer (degree)	November 2017
Nuclear reactor desk engineer	In development
Nuclear scientist and nuclear engineer (degree)	September 2015
Packaging professional (degree)	June 2018
Product design and development engineer (degree)	November 2014
Project controls professional	In development
Project manager(degree)	June 2018
Quality leader	In development
Rail and rail systems senior engineer (degree)	July 2018
Science industry process/plant engineer (degree)	February 2018
Space engineer (degree)	In development
Supply chain leadership professional (degree)	December 2018
Tool process design engineer	In development

[1] Data from Institute for Apprenticeships and Technical Education

Appendix C - Skills Matrices from the Made Smarter Review

The three skills matrices form the made Smarter Review (Maier, 2017):

MATURE SKILLS – ALREADY EXIST AND USED	LEVEL 1	LEVEL 2 Semi - skilled Intermediate Apprenticeship	LEVEL 3 NC/ND (Engineering Technician) Advanced Apprenticeship	LEVEL 4 HNC/HND/FD (Incorporated Engineer) Higher Apprenticeship	LEVEL 6 Bachelor's degree (Incorporated Engineer) Degree Apprenticeship	LEVEL 7 Master's degree (Chartered Engineer)
Programming software			✓	✓	✓	✓
Mechatronics			✓	✓		
Processing of data			✓	✓	✓	
Material and production skills		✓	✓			
Process skills		✓	✓			
Electrical engineering/systems			✓	✓	✓	
Electronics			✓	✓	✓	
Maintenance, servicing, and further development of the system (robotics)		✓	✓			
Mechanical and plant engineering		✓	✓			
Product design				✓	✓	✓
PLC Programming				✓		
Specify, install and setup control systems hardware				✓		
Value Stream Mapping and LEAN principles			✓	✓	✓	

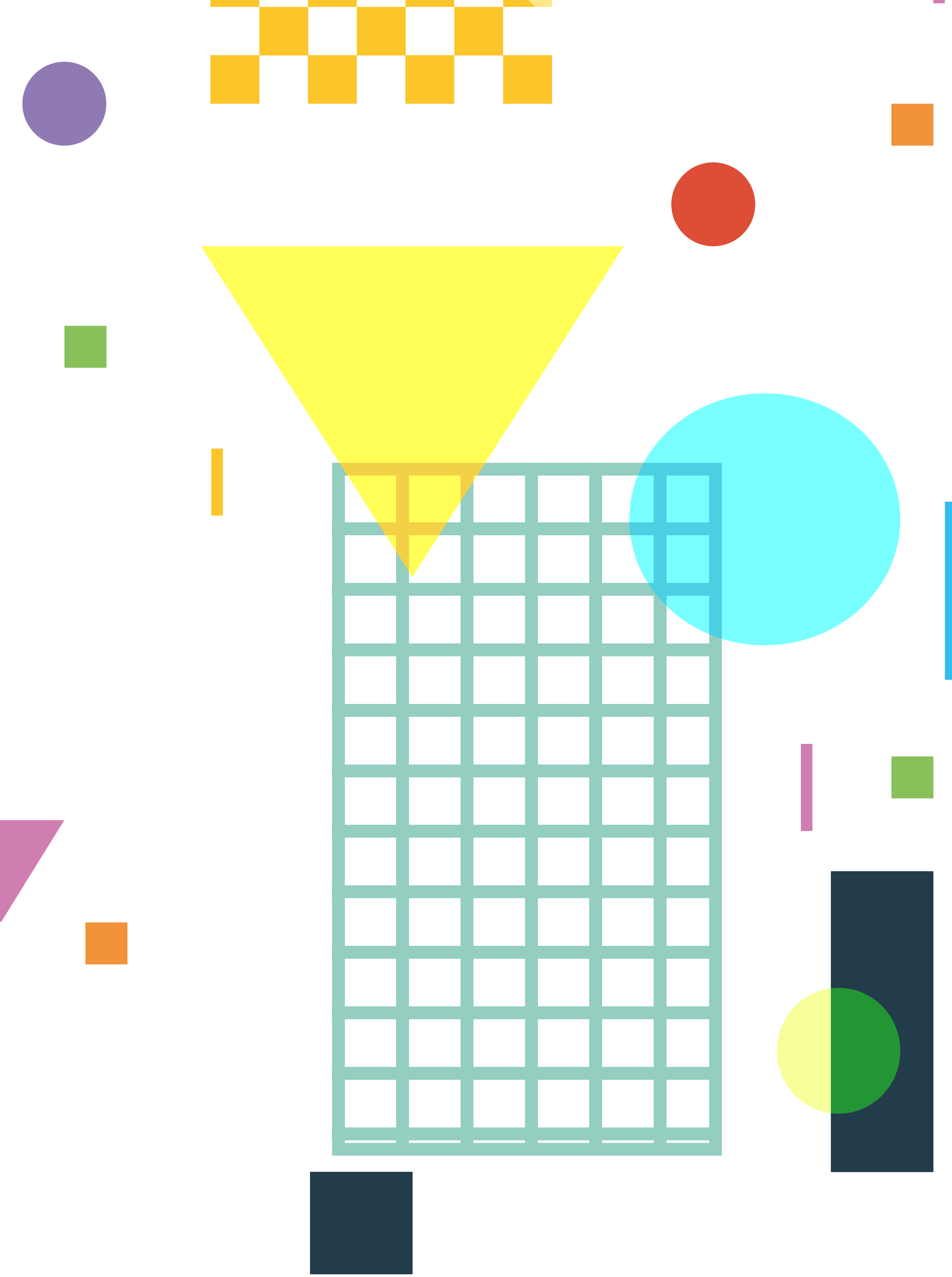
Figure C1: Skills in common use

SKILLS CURRENTLY USED IN A LIMITED WAY	LEVEL 1	LEVEL 2 Semi - skilled	LEVEL 3 NC/ND (Engineering Technician)	LEVEL 4 HNC/HND/FD (Incorporated Engineer)	LEVEL 6 Bachelor's degree (Incorporated Engineer)	LEVEL 7 Master's degree (Chartered Engineer)
Computer network skills				✓	✓	✓
Data science			✓	✓	✓	
Rapid prototyping – CAD software, 3D printing, advanced injection moulding			✓	✓		
Robotics – software and programming skills and engineering ability				✓	✓	
Data interpretation/mining – plus making use of Big Data and informatics			✓	✓	✓	
Optimisation, monitoring and controlling of processes			✓	✓	✓	
Industrial networks control systems (HMIs, SCADA etc)				✓		
Proportional hydraulics (PLC controlled)			✓	✓		
Systems Engineering				✓	✓	✓
Data management/leadership				✓	✓	

Figure C2: Skills likely to be used more frequently in the short term

NEW/EMERGING SKILLS – NEED FOR FUTURE						
	LEVEL 1	**LEVEL 2** Semi - skilled	**LEVEL 3** NC/ND (Engineering Technician)	**LEVEL 4** HNC/HND/FD (Incorporated Engineer)	**LEVEL 6** Bachelor's degree (Incorporated Engineer)	**LEVEL 7** Master's degree (Chartered Engineer)
Computer security software skills			✓	✓	✓	✓
Artificial intelligence				✓	✓	✓
Using virtual and augmented reality				✓	✓	✓
Human-machine interaction (HMI) skills					✓	✓
Predictive analytics			✓	✓	✓	✓
Automation technology			✓	✓		
Microsystems technology			✓	✓		
Appreciation of digital technologies	✓	✓	✓	✓	✓	✓
Intelligent application of digital technologies			✓	✓	✓	
Digital leadership				✓	✓	✓
Digital creativity (creation of product digital twins, creation of production line digital shadows)					✓	✓
Interface management/leadership				✓	✓	
GENERIC SKILLS	Complex problem solving, critical thinking, creativity, people management, change management, coordinating with others, emotional intelligence, judgement and decision making, service orientation, negotiation, cognitive flexibility (Source: WEF) Sense making, social intelligence, novel and adaptive thinking, cross cultural competence, new media literacy, transdisciplinarity, design mindset, cognitive load management, virtual collaboration (Source: Future of Work 2020, Institute for the Future) Customer relationship management – crucial if benefits in vertical integration are to be involved. Creation of new business models at a more senior level					

Figure C3: Skills likely to be more in demand in the longer term



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