UK-RAS White papers

ISSN-2398-4422
DOI: 10.31256/WP2021.1

UK-RAS NETWORK
ROBOTICS & AUTONOMOUS SYSTEMS

Preparing the workforce for 2030: **Skills and Education for Robotics & Autonomous Systems**

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FOREWORD

PREPARING THE WORKFORE FOR 2030
SKILLS AND EDUCATION FOR ROBOTICS & AUTONOMOUS SYSTEMS

Welcome to the UK-RAS White Paper Series on Robotics and Autonomous Systems (RAS). This is one of the core activities of UK-RAS Network, funded by the Engineering and Physical Sciences Research Council (EPSRC). By bringing together academic centres of excellence, industry, government, funding bodies charities, and the public, the network provides academic leadership and expands collaboration with industry while integrating and coordinating activities at EPSRC-funded RAS capital facilities, Centres for Doctoral Training and partner universities.

Across the world, and here in the UK, industry and commerce are undergoing a 4th industrial revolution (4IR) that will bring about a step-change in UK productivity whilst also transforming how people interact with, and work alongside, digital systems and smart machines. At the heart of this transformation are RAS technologies.

These are exciting times, however, the UK is faced with significant challenges. Amongst the most important are the need to reskill the current workforce to work safely and effectively alongside robots, to train managers to understand and effectively deploy automation, and to ensure that, across all levels of education, people from diverse backgrounds have the skills they need to be part of the 2030 workforce. In this white paper we summarise these opportunities and challenges, identify promising recent initiatives in skills training, both in the UK and across the world, and identify future interventions in UK RAS education that are both affordable and scaleable, and that could help the UK maintain its place as a leading technological economy.

The UK-RAS White Papers are intended to serve as a basis for discussing UK industrial and social strategies and for engaging the wider community and stakeholders, as well as policy makers. It is our plan to provide future updates for these white papers so your feedback is essential—whether it be pointing out inadvertent omissions of specific areas of development that need to be covered, or major future trends that deserve further debate and in-depth analysis.

Please direct all your feedback to info@ukras.org. We look forward to hearing from you!

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We would like to thank the members of the UK-RAS SERAS Strategic Task Group, which includes representatives of 18 public, not-for-profit and for-profit organisations (see https://seras.org.uk for full list), who have contributed their advice and ideas. We would like to especially thank Philippa Glover of CNC Robotics, Mark Gray of Universal Robotics, Laura Cumming and Duncan Russell of Ocado, Julie Walters and Stewart Powel of Technocamps, Ed Cervantes-Wilson of FIRST Robotics, Niki Jones of the AMRC, Robert Bush of Additive Automations and Alan Oakley of Kuka Robotics for the time that they took to record interviews with us. Much of the work for this report was undertaken between October 2020 and March 2021 during the COVID-19 pandemic and its restrictions on travelling and social distancing prevented in-person visits or meetings with the interviewees and locations covered in this report. Interviews were instead conducted online and recorded.

Conflicts of Interest
RW is a director and shareholder of Cyberselves Universal Ltd which develops robotics middleware and telepresence solutions. PC is a co-founder and co-director of Creative Digital Solutions Ltd, a design agency for embedded digital strategies. TJP is a director and shareholder of Cyberselves Universal Ltd and of Consequential Robotics Ltd which develops robotic solutions for research, education, and healthcare.

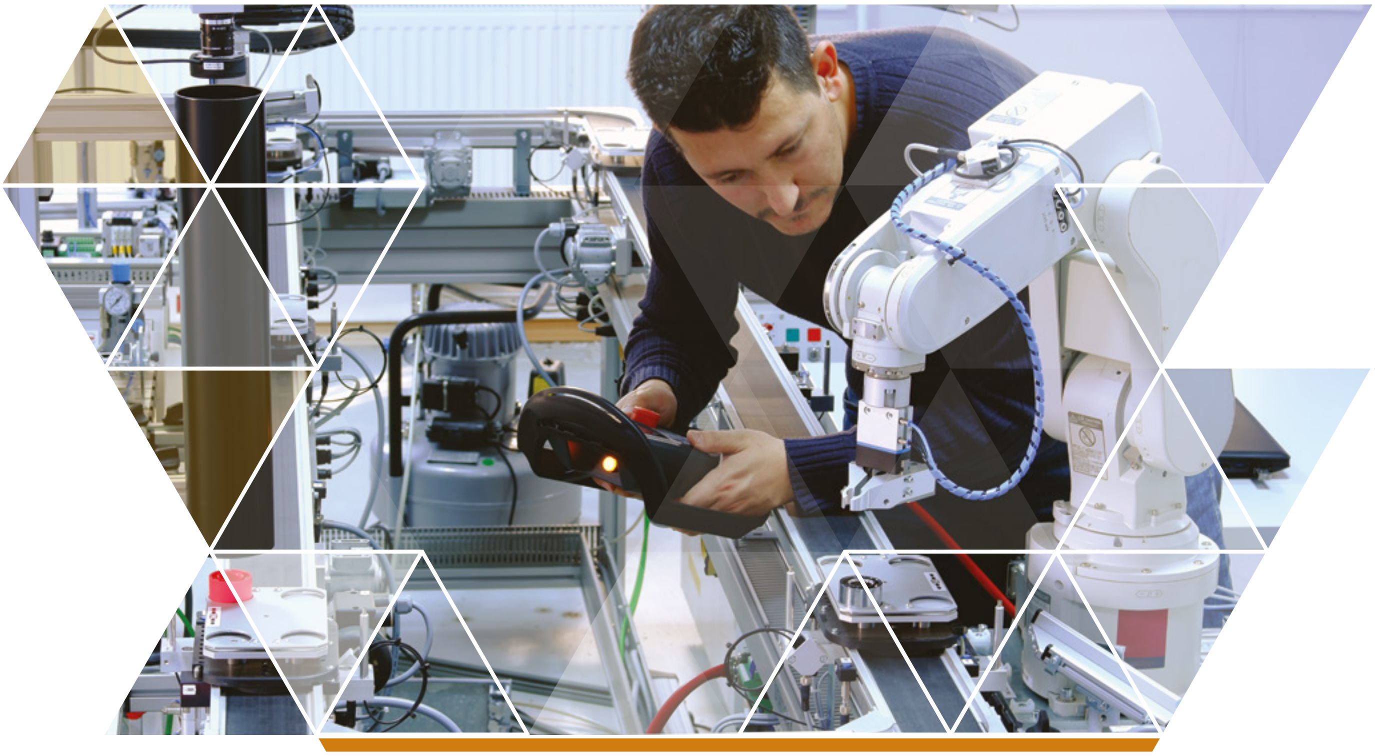
EXECUTIVE SUMMARY

Widespread adoption of autonomous systems, realising the cost and efficiency benefits of robotics and *artificial intelligence* (AI), is a necessity for 21ST century economic success and offers a golden opportunity to reshore manufacturing and boost the UK's productivity and output. However, we face an unprecedented skills challenge in preparing our labour force to work with these technologies.

Some of the most burning issues facing us include: a lack of practical hands-on experience of robotics and technical skills at all education levels; limited management understanding of emerging technologies; failure to address diversity and inclusion; and an education system that is struggling to provide the skillsets required by employers. A further concern is the current 'hub-with-no-spokes' knowledge and skills diffusion network, in which the excellence of our universities and best-performing companies too often fails to impact and support the emerging *Small and Medium Size Enterprise (SME)* sector and others far from the centre.

Major new government initiatives such as the National Retraining Scheme, the Apprenticeship Levy and the Skills Toolkit show a government willingness to address these challenges and offer genuine encouragement that the UK can close the skills gap, assuming that such schemes can be funded and scaled sufficiently.

To add to these welcome interventions, we advocate providing free public access to genuinely high-end robotics resources, digital and actual, that will enable the practical and tangible experience of RAS technologies that the future workforce needs. Robotics Learning Factories, inspired by models such as *FabLabs, Newton Rooms* and the manufacturing *Learning Factories*, that have been so successful in Germany, the US, and Scandinavia, can be linked to local mini-hubs situated in libraries or other public buildings. Bridging between educational levels, supported by industry, and harnessing technologies such as *digital twinning*, 5G, and *tele-operation*, this network of facilities would provide accessible learning experiences that accurately reflect emerging work settings. An intervention of this kind would be timely, affordable, scalable, and could be realised quickly to help address the skills gap and position the UK as a leading economy in the *4th Industrial Revolution (4IR)*.



> The reach and capability of autonomous systems is growing rapidly, displacing and creating employment chances at an accelerating rate. For the UK to take advantage of such an opportunity, it is vital that policies and resources, including educational and training systems, are put in place quickly to help the workforce adapt and prepare for the future workplace.

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"Brexit, in the UK, has added extra urgency to the need for the increased adoption of robotics, with labour shortages threatening many of the UK's industries. The workplace of 2030 will be a different place than it is today, with robots performing many of the tasks now carried out by humans, and with human workers doing jobs that involve working with robots that do not even exist today."

1. INTRODUCTION

There are three times as many robots than there were two decades ago [1], with over two million robots now utilized in manufacturing and the service sector across the world. The number of robots has doubled in just the last ten years and the rate of adoption worldwide is set to accelerate at an even faster rate, with recent innovations in engineering and machine learning, let alone the highly disruptive effects of the COVID-19 pandemic. The rapid adoption of digital communication technologies during the pandemic has been seen by many as a vanguard of *4IR* (4th Industrial Revolution) technology adoption, allowing more complex technologies to follow in their tailwind.

Where robotics was principally an industrial technology pre-2020, it is now widely predicted to transform the service sector, with healthcare especially seeing a significant rise in adoption to mitigate the risks of cross-infection. Robots are now seen as a key solution to keeping humans safe in hazardous environments, be they hospitals, space, or battlefields.

Brexit, in the UK, has added extra urgency to the need for the increased adoption of robotics, with labour shortages threatening many of the UK's industries. The workplace of 2030 will be a different place than it is today, with robots performing many of the tasks now carried out by humans, and with human workers doing jobs that involve working with robots that do not even exist today.

Just as previous industrial revolutions have been described as "a race between education and technology" [2], so the current technological revolution - fuelled by the rapidly developing technologies of robotics, *AI*, *autonomous systems* and data science - will require a programme of skills and educational provision that is as innovative, and as urgent, as the technologies that it aims to keep pace with.

Part One of this White Paper will investigate the extent of the skills gap around robotics and autonomous systems in the UK today, paying particular attention to the significant gaps in technical education and management, the ongoing issue of a diversity imbalance, and the lack of practical education and skills provision. Part Two will explore potential solutions, with an analysis of the skills required for the workplace of 2030, and of the benefits of tangible, experiential learning that prioritises problem-solving. It will also examine best international practice in technology skills provision, including *Learning Factories*, arguing for the importance of using robots in education to give learners more practical experience of this key emerging technology.

Part Three will conclude that creating a national repository of high-end robotics resources, actual and digital, represents a scalable, affordable and effective way to allow people to access the skills that will enable them to thrive in the 2030 workplace.

PART 1

2. EMPLOYMENT AND TECHNOLOGY

Past disruptive technologies such as mechanization, electricity, digitalisation, and the advent of the internet initially replaced human labour in previous Industrial Revolutions, yet such technologies ended up creating new jobs and offering better working conditions. Rapid technological change was accompanied by an overall positive effect on employment growth [3].

The rapidly developing capabilities of autonomous systems, however, are thought to herald a new machine age that will dwarf previous waves of innovation in terms of the scale, speed, and scope of the disruption that it creates. Machines can now perform many previously human tasks better than the workers that they threaten to replace. They can also do so at lower cost, and more reliably, offering business and manufacturing the opportunity to increase productivity, make their systems leaner, and more predictable and efficient, with cost no longer such an inhibiting factor. Every newly installed *industrial robot* is estimated to displace 1.6 human workers [4]. By 2030, 20 million additional manufacturing jobs will most likely be lost to automation worldwide [5]. The service sector, relatively untouched by automation until now, will see similar labour displacement as robots and autonomous systems become more capable and effective and prices fall.

The speed and scale of automation suggests that productivity gains in adopting autonomous systems could dwarf even those experienced in the first industrial revolution, with estimates predicting a rise of 0.8-1.4% over the next fifty years, compared to the 0.3% growth in productivity over the last half of the nineteenth century [6].

A 1% increase in the stock of robots per worker in the manufacturing sector leads to 0.1% boost to output per worker across the wider workforce. The automation of cognitive skills, let alone industrial functions, could have as wrenching and lengthy an impact on the jobs market as the first industrial revolution [7].

Yet this process of creative destruction, which will see many existing jobs displaced by autonomous systems, is not as bleak for employees as it first appears. Instead, it is expected that new employment opportunities will be generated at a comparable or even higher rate [8]. The challenge is that these new jobs will require very different skill sets to those that they replace. Without upskilling workers to work with emerging autonomous systems, the UK will fall behind its competitors in grasping the social and economic opportunities that *4IR* offers. Thus, while automation could enable the UK to boost its currently poor rate of productivity, this can only happen if education can keep pace with technological development, even with technology moving so fast.

The reach and capability of autonomous systems is growing rapidly, displacing and creating employment chances at an accelerating rate. For the UK to take advantage of such an opportunity, it is vital that policies and resources, including educational and training systems, are put in place quickly to help the workforce adapt and prepare for the future workplace.

3. THE UK SKILLS GAP

The statistics highlighting the UK skills gap are becoming well-worn but continue to undermine the government's aim to establish the UK as a world-leader in new technologies by 2030. While the UK is indeed highly competitive in the quality and number of its technology graduates and postgraduates – and the renown of the academic institutions delivering them – skills attainment below university level remains poor in comparison with many of the UK's competitors [9]. There is a dearth of skilled technicians below degree level (level 6); a wider workforce often devoid of requisite skills in numeracy, literacy, and STEM; and a layer of management whose lack of general technological facility can inhibit its ability to adopt and integrate the autonomous systems that modern manufacturing and business increasingly require.

Employers also report a debilitating lack of practical skills in workers from all educational levels. Engineering and computer science graduates are said to lack hands-on experience of the technology that they have been educated to utilise [10] while employers also complain of struggling to find up-to-date practical training for technician apprentices on modern equipment and emerging technology [11]. The provision of relevant hands-on technical education in the UK, where participants should be able to operate and interact with the emerging technologies that they will work with in later life, remains limited [12].

A lack of practical hands-on experience of *4IR* technologies is also hampering the ability of schools to prepare children for the future workplace. An artificial creation of discipline boundaries and an educational approach driven by theory more than practice and application have led to a shortage of technician-level STEM skills and overall competence in technology. A more authentic, experiential approach would help learners develop a deeper understanding and resilience in solving problems in the future workplace, using technology as a tool [13].

More resources should be offered to schools to help them close this gap. We should build upon much of the excellent work over the last five years of extra funding and focus on STEM skills in school education and continuing professional development (CPD) for teachers [14], by augmenting them with experiential robotics and AI programmes. Robotics and autonomous systems are currently transforming the workplace, yet do not feature in the curriculum. Schoolchildren must be given better access to such technologies if the UK economy is to thrive in the decades to come.

4. TECHNICAL EDUCATION & SKILLS PROVISION

Although we face an annual shortage of approximately 45,000 technicians [15], technical education uptake in the UK is significantly lower than that of many of its competitors. Only 10% of the workforce hold a non-degree technical qualification above A level (levels 4-5) as their highest level of attainment in the UK, less than half the rate of competitors such as Germany [16], despite the pull of higher wages and increased employment opportunities for those with technical skills at this level.

With many of those holding such technical know-how shortly due to retire from the workforce, the current position will be hard to turn around [18]. The UK is the only country in the G7 where older workers over 50 are more proficient in numeracy than 16-24 year olds [19].

With a series of government reports [20] highlighting the lack of non-academic accredited pathways to practical technical employment – and the lack of opportunity for older workers already in employment to upskill themselves in the use of emerging technologies – a number of skills initiatives such as the *Apprenticeship Levy, T Levels,* the *National Retraining Scheme* and the *Skills Toolkit* [21] have been established to forge coherence and clear pathways in technical education. Such a battery of initiatives that directly address the skills gap in technical education at levels 4-5, speak of the government's acknowledgement of the urgency of the issue. We hope that their ambition to carry such a programme through can be matched with sufficient funding to provide requisite expertise and resources throughout the regions of the UK, scaling sufficiently quickly to keep pace with technological change and the efforts of international competitors.

As seen in countries such as Germany, Switzerland, France, and Canada, that are recognised as leading in skills training, the UK is seeking to establish a regionalised demand-led system whereby local employers generate demand for particular skills training which is then provided by local training organisations. Signs are encouraging; the recently-announced and relatively well-funded *Adult Education*

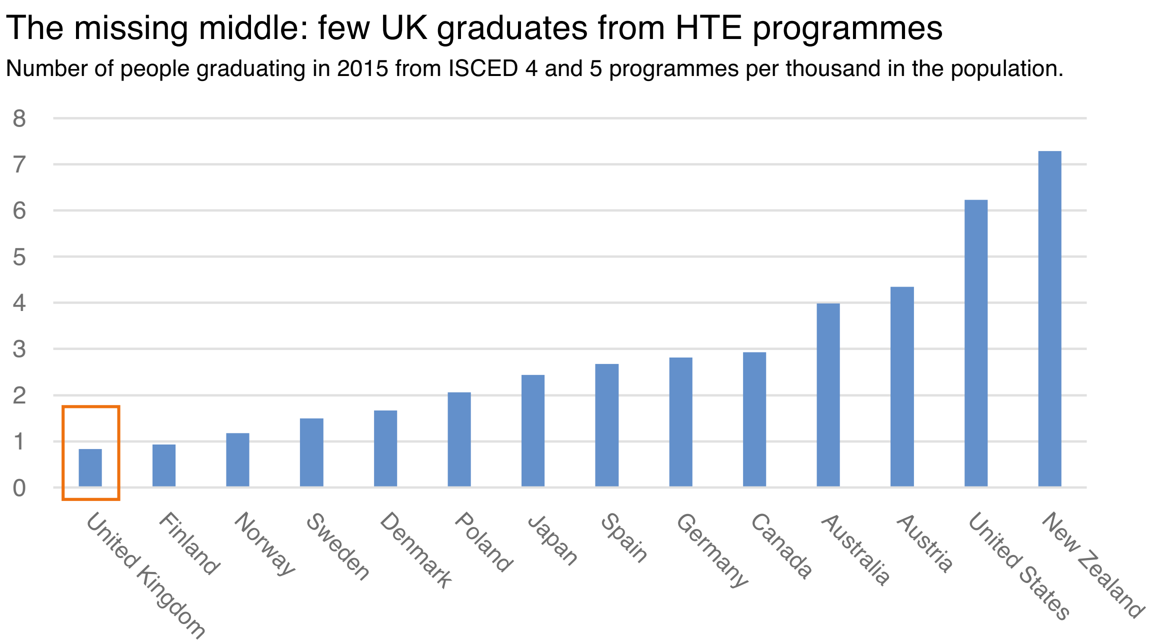


FIGURE 1.

Number of people completing a level 4-5 programme per thousand in the population [17]) with: 'Reproduced from The Missing Middle: Higher Technical Education in England (2018) by Simon Field for the Gatsby Foundation. Data sourced from the OECD education database [17]'.

Budget (AEB) [22] has given regions the chance to develop local strategies around the specific skill sets required by local large employers – twenty one colleges in the West Midlands, for example, have formed a bespoke skills collective to deliver training [23] – but we should be careful to listen to the employers with specific training needs, such as in robotics and autonomous systems, who complain of not being able to access the particular training that they need [24].

The two years up until Q1 2019 saw an underwhelming 18% uptake among levy-paying large employers of the funds made available to them for new apprenticeships [25], often because they are unable to find the requisite training sufficiently nearby [26]. Graduate apprenticeships are generally held to be successful, especially among training providers and students for whom such training is free, but from the perspective of employers, the system is often seen as too inflexible, with insufficient funding and scale in the provision of suitable post graduate degree courses, and graduate training often lacks practical experience and expertise in new technologies. Several larger employers see the levy as little more than tax.

It is hoped that UK government can also effectively address the difficulty that non-levy payers have experienced in accessing suitable training on the graduate apprenticeship scheme. Of 51 approved degree apprenticeship standards, 43% have no providers able to deliver to non-levy payers - the *SMEs* that make up 98% of businesses in the UK. The UK leads Europe in the dynamism and commercial opportunity offered by a booming *SME* technology sector. There are over twice as many small companies in AI in the UK compared to Germany, for example, and four times as many as in France [27]. It is mostly from *SMEs* that job growth will emerge. The city of Sheffield alone, for instance, houses 45,000 SMEs, many in technology, yet as non-levy payers, they are currently offered the choice of no provider or just one provider for 32 of the 51 approved degree apprenticeship standards nationally [28]. If *SMEs* are to drive increased employment and productivity, and accelerate the rate of adoption of autonomous systems, they must be given better access to high level technical training resources and skilled staff.

5. MANAGEMENT SKILLS

The occupational group least likely to participate in technical training is that of management [29]. Over two thirds of organisations in the UK acknowledge that they fail to effectively train first-time managers [30]. In technological *SMEs* especially, such a skills shortage at management level has led to low adoption and diffusion rates of emergent technologies and of the lean, agile manufacturing processes facilitated by autonomous systems and collaborative robotics. The UK accounts for less than 5% of European shipments of *industrial robots* and under 1% of the global annual total. Of the other six G7 nations, the UK has the lowest adoption rate, recently at less than 10% of that of Germany, the US, and Japan [31].

Without the managerial structures and processes enjoyed by several of the UK's competitors to identify and integrate new technology into manufacturing and business, a lack of technological awareness among the UK's managers has limited the ambition of their decision-making and planning in terms of innovation, which has led in the past to poor productivity, wasteful manufacturing techniques, and low-quality products [32]. An overly long return on investment (ROI) has previously been seen as a major barrier to the adoption of automation in the UK, with cost also being viewed as prohibitive, but advances in robotics generally, and especially in *cobotics*, has significantly shortened the ROI on automation as well as hugely improving its ease-of-use [33]. If managers can be helped to see the benefits that automation can bring and better visualise what automation now looks like with the aid of better training resources, companies will be able to embrace the more flexible forms of manufacturing employed by many of their competitors and reverse the decline in productivity that has bedevilled the UK economy over the last decade.

6. DIVERSITY

Though many of the early pioneers of computing were female, women now account for only 20% of the STEM workforce. The UK has the lowest percentage of female engineering workers in Europe, at less than 10% [34]. Engineering, robotics, electronics, and AI are dominated by men in the boardroom as much as the factory floor. Such a lack of diversity inhibits decision-making in a company, with numerous studies attesting that diversity in problem solving can be more important than ability and is vital to driving innovation in a company [35]. As well as shrinking the pool of available skilled workers and managers, a lack of diversity denies women the opportunity to work with the latest emerging technologies.

Recent reports such as that of the Strategic Transport Apprenticeship Taskforce, however, suggest that there may be some hope in righting the gender imbalance. The percentage of women starting technical engineering apprenticeships has risen from 10% to over 15% in the last two years [36]. Although it is hard to pinpoint the cause of such a rise, proactive gender balancing can be successful in increasing diversity, with the Taskforce's overt three-year plan to attract more women into engineering and technical apprenticeships shown to be bearing fruit. By demonstrating clear advancement pathways and potential role models in the industry, the initiative can serve as a useful model for other such workplace schemes.

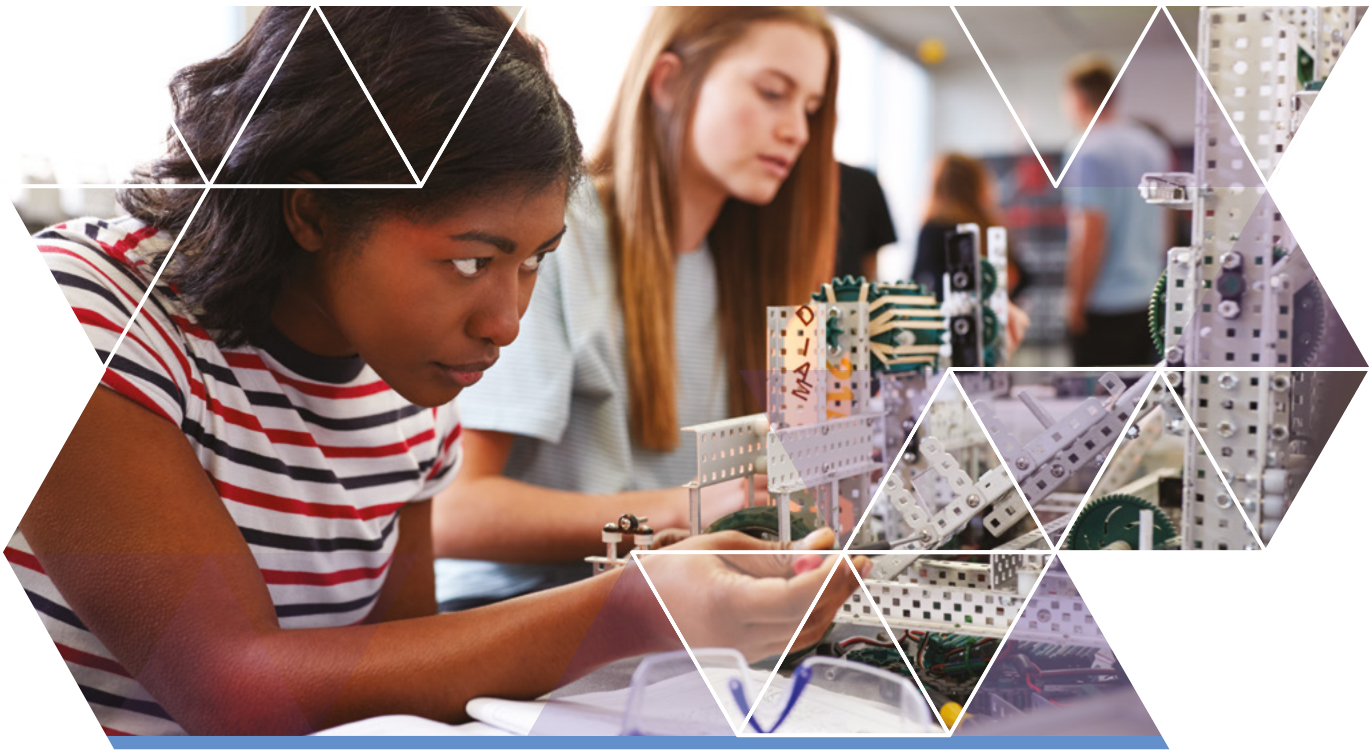
Key to assessing the efficacy of different approaches to righting the gender imbalance in technology will be the harnessing of more data and evidence. Particular attention should also be paid to the importance of disaggregating data based on gender so that we can mitigate against gender biases, or the 'gender gap' [37], in much current data analysis. We eagerly anticipate results from the *National Centre for Computing Education (NCCE)* Gender Balance in Computing programme, a collaboration between *STEM* Learning and the Raspberry Pi Foundation among other organisations [38]. The NCCE programme is a four-year research project involving 1,000 schools in the UK and seeks to investigate best practice in attracting girls at school into science. The Open University's INSPIRE project similarly aims to generate evidence of best practice in integrating congruent *4IR* technologies such as robotics, AI, and the *Internet of Things (IoT)* into the current curriculum in schools as an engagement and further learning strategy.

A further example of good practice is the Welsh extra-curricular computer studies skills training initiative, *Technocamps*, which is aiming for a two thirds female gender balance in its current project cycle, having managed a 50:50 split in previous projects. The importance of establishing strong role models is again highlighted by *Technocamps*, whose women in STEM network (WIST) brings female professionals to schools to discuss their work in the industry. Such initiatives also stress the value of presenting computing and engineering in more relevant, imaginative ways when attempting to attract girls and women to the subject. CS can be better seen as computational thinking, for example, presented in terms of real-world problem-solving relevant to daily life, instead of an esoteric learning largely pursued by men. The notion of "challenges" where participants are encouraged to devise a problem in their own environments and design a solution to it using technology, has also helped to reframe technological skills provision to encourage female take-up.

Out-of-school initiatives and new international technology-themed competitions such as *Lego MindStorms*, and the international robotics competitions and invention programmes staged by organisations such as *FIRST* and *WER*, let alone the ambassadorial work of *STEM Learning* and the *BBC Micro:Bit project*, have helped alleviate the gender imbalance in STEM subjects at school, with 70% more girls saying they would choose computing as a GCSE subject after trying out a Micro:Bit, for example. However, the ratio remains low and there is no doubt that the UK's overall engineering skills deficit and workforce would be significantly impacted if more women could be attracted to STEM school subjects and careers.

Diversity is not only a matter of gender. As well as male, the STEM workforce is overwhelmingly white and able-bodied – which again only provides a shallow pool of skills, backgrounds, and opinions for employers to involve in company decision-making and innovation strategies. Although ethnic minority groups are better represented proportionally than their white counterparts in STEM degrees, there are fewer who go on to successful STEM careers [39]. The situation has failed to improve over the last five years, with similar statistics from 2016 demonstrating that unemployment rates among minority ethnic engineering graduates were higher than those of their white colleagues [40]. With more research to gather the data to help right such an imbalance, such as that recently conducted by the *Royal Society* [41], there is no reason why ethnic minority participation in the STEM workplace should not significantly improve, especially in light of the preference of ethnic minority students to choose STEM over non-STEM subjects at university and school [42].

With far less data published about the issue of disability in STEM workplace diversity, further research is urgently needed. People who define themselves as disabled are certainly less likely to take a STEM degree than a non-STEM one, however, general participation rates in further education do appear to be rising. We should note, though, that these figures are skewed by the large recent increase (of over 1,000% between 2008 and 2018) in the number of STEM students who report a specific learning disability or mental health condition. What is not in doubt is that a higher proportion of disabled STEM graduates meet unemployment after graduation than their counterparts with no known disability. Notably, it is graduates with social communication/autism spectrum disorders that suffer most in finding employment [43]. With an increasing body of evidence highlighting the positive effect of introducing social robots into the education of learners on the autistic spectrum, and the enhanced engagement with robots often experienced by autistic people [44], we must ensure that sufficient research and attention is paid to encouraging more people with such disabilities to pursue careers in robotics and autonomous systems.



"Roughly 50% of people from lower social groups were unable to access any training since leaving school, compared to 20% of those from the highest social group. Such social exclusion from post-school training is set to widen existing skills gaps in the UK and leave less-advantaged communities more vulnerable to job replacement by automation in the coming years."

7. ADULT SKILLS TRAINING

Reskilling the current workforce is widely seen as the UK's biggest challenge in keeping pace with the accelerating prevalence of autonomous systems, yet the UK currently lags behind the vast majority of its competitors in skills provision for people of a working age. One in five UK firms report that they are unable to find workers with basic digital skills, while 53% of the working population are estimated to lack basic digital skills needed for the workplace, such as sharing and attaching documents to an email [45]. About six million adults, one in five of the UK workforce, do not have the equivalent of a Level 2 qualification [46] in any subject, and 49% of the current workforce - 17 million adults - lack the everyday maths skills of a Year 7 school pupil [47].

Compounding the issue is that people from the lowest socio-economic backgrounds are the least likely to receive adult skills investment [48]. Roughly 50% of people from lower social groups were unable to access any training since leaving school, compared to 20% of those from the highest social group. Such social exclusion from post-school training is set to widen existing skills gaps in the UK and leave less-advantaged communities more vulnerable to job replacement by automation in the coming years, amounting to a 'virtuous' and a 'vicious' cycle of inclusion in learning, in which those with fewer qualifications are less likely to get the education and training that they will require to thrive in the workplace of 2030, whereas the better qualified are likely to receive the most.

Over three quarters of the 2030 workforce are already in work. Although the new generation of *mechatronics* engineers and software developers will most likely be drawn from those currently in full-time education, the vast majority of those who will be working with the autonomous systems of the next decade will be drawn from the current workforce. The UK will not have to conjure a host of programmers and robotics engineers to populate the 2030 workplace, but it does need to develop a workforce, through training, that is eager and able to work with these new machines.

Specific expertise will be vital, but as important is to generate a broad-based understanding and facility with technology, along with a willingness to reskill as technology advances throughout one's working life [49]. Collaborative robotics and easy-to-use interfaces will mean that even adults currently working in non-technological roles will be able to control robots or work with autonomous systems in the future if they are helped to engage with such technologies now.

One concerning development is that the *Adult Participation in Learning Survey*, recently administered by the UK *Department for Education* (DfE), featured the lowest number of adult workers in the survey's 23-year history. Only a third of adults confirmed they had participated in learning during the previous three years and 38% indicated that they had not received any training since leaving full-time education. The reasons given by respondents for such low participation figures do provide an indication as to how to attract more people to adult learning - if costs were lower, home learning were easier, and if courses better reflected their needs, participants noted that they would indeed be more likely to take up, or increase, their learning [50].

PART 2

8. 2030 WORKPLACE SKILLS

For workers to thrive among the emerging autonomous technologies, they will need to be ‘T-shaped’ in their skill acquisition [51], with a vertical understanding in a particular technology, and a broad understanding of technology generally. Such widespread digital literacy emerges along with critical thinking, collaboration, communication, and most of all creative problem-solving as the skills that most employers and educators cite as those that will be needed in the future workplace.

Main Qualifications/Skills needed for the workplace

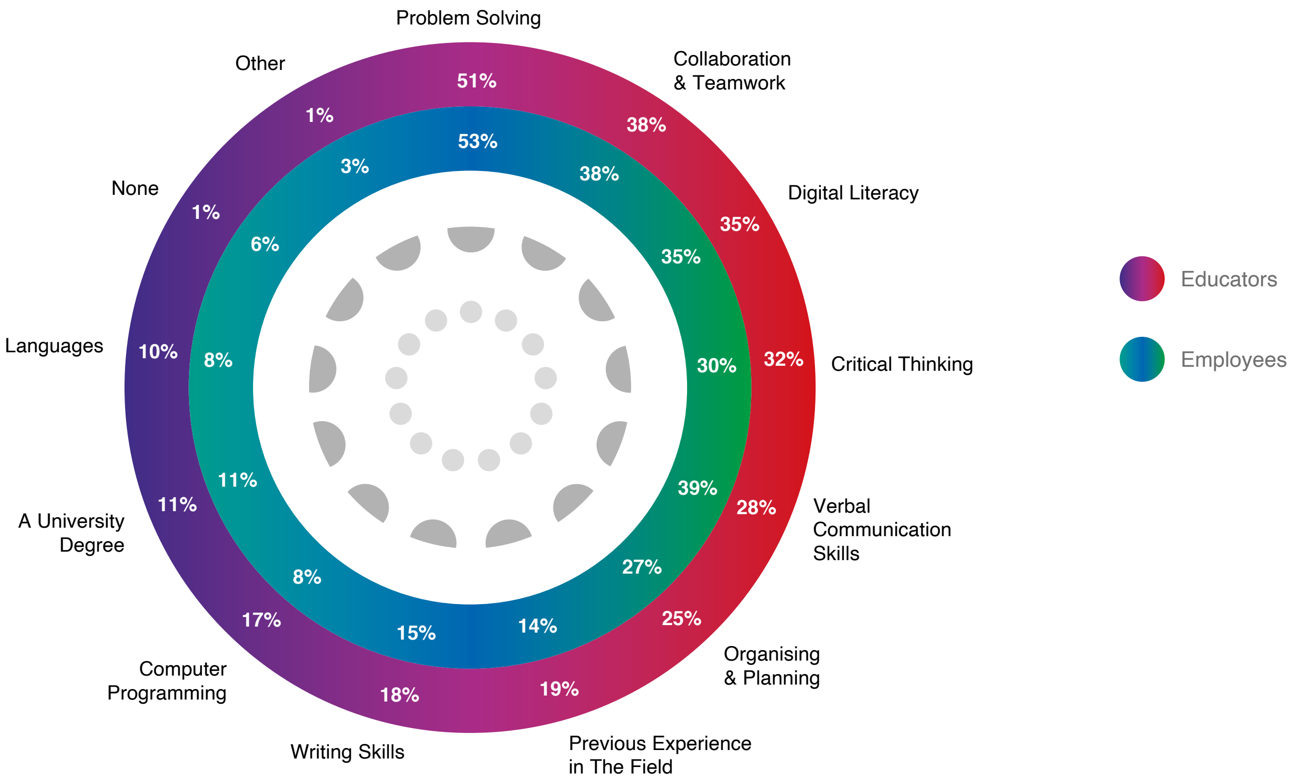
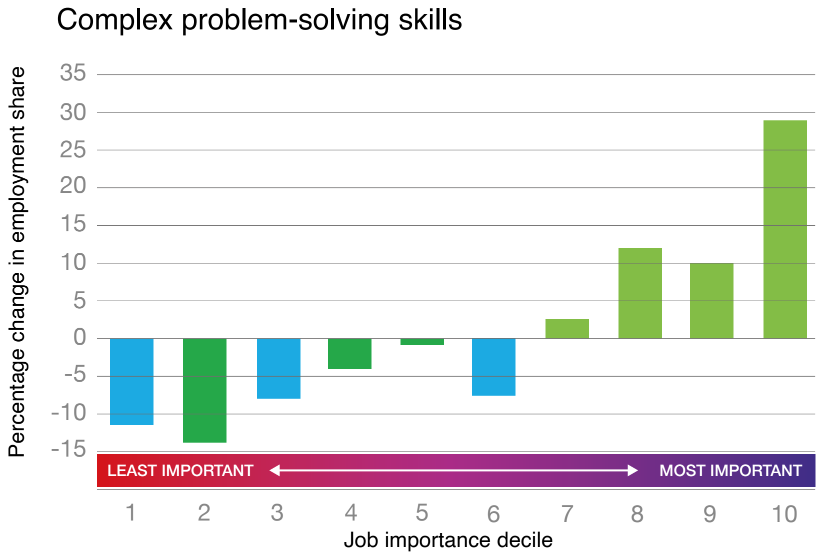


Figure 2
Source: Censuswide survey of 1,000 businesses and 500 secondary school teachers. Taken from Skills Study – Preparing for the Workplace. Instructure. 2019.’

These are the ‘human’ skills that can enhance and step in for AI in less predictable situations and which continue to be irreplaceable in many employment roles [52]. In a recent survey (Figure 2), 53% of employers stated that problem solving is the prime skill that they seek in new employees, and yet it hardly features in the curriculum and is barely accessed in adult skills training. In the specific context of robotics and autonomous systems, what the workforce of 2030 will be required to do is problem solve alongside the machines and technologies of *4IR* [53].



Caption: Deloitte's survey of skills for the machine age found that although specialist STEM knowledge is 40% more important than physical traits such as strength or flexibility, general purpose complex problem-solving skills are over twice as important [54]. *Fig 3 (left) demonstrates that skillsets such as complex problem-solving have a positive relationship with employment share and that jobs at the lowest risk of automation are those where problem-solving has the highest importance* [55].

Figure 3
The Positive Effect of Complex Problem Solving on Employment Share. Source: O*NET, ONS, Deloitte analysis. Deloitte LLP 2016

Integrators, such as CNC Robotics, tell us that their hiring sweet spot is a candidate who can problem solve creatively, designing engineering solutions to problems using robotics. Being able to think strategically and creatively, using technical resources as tools to facilitate solutions, and being able to think on one's feet in applying knowledge practically, are key problem-solving skills that employers increasingly seek. It is a can-do attitude and resilience that can keep pace with technological progress in applying knowledge, and an eagerness and volition to engage with and take responsibility for technology in the workplace; learning how to use technology as a tool rather than just learning about technology.

Code for Life

Problem-solving is at the heart of the open source learning software that Ocado have made available to schools throughout the UK in their Code For Life campaign, which originated as an initiative to improve their pipeline of future skilled workers. Although the gamified learning experiences in Code for Life are ostensibly designed to pull learners through an elementary engineering or software design process, it is equally the process of problem solving using technical tools that they wanted to draw out.

Experiential, tangible learning can appear more useful and relevant to people's lives and working needs, making it more likely that they will pursue further learning to keep their skills up to date. Where the contents of maths, physics, computer science, and other siloed subjects of more traditional education can appear irrelevant and distant to learners, creative problem-solving and experiential learning can offer participants multiple pathways and entrances to technology.

Such a multidisciplinary approach also reflects the likely employment and requisite skills landscape of 2030. If the ideal profile of future *4IR* workers is that they should have a wide and general understanding of technology, then it is important that current learners be drawn from as wide a pool as possible.

Competitions

Technology competitions and challenges, such as those run by FIRST and WER, embody many of the characteristics of tangible, experiential learning and have proved highly successful in engaging people in robotics and related technologies. Contestants work in teams to build robotic solutions to problems that need to be solved. The competitions are often international and performed on a large scale with drama and pizzazz in stadiums to gamify the team learning experience and widen its appeal.

As well as problem solving and collaboration, competitions utilise critical thinking and communication – the four skills most in demand by employers. So developed is the competition ecosystem in the US, with schools and organisations competing year after year, that several employers prefer the events to recruitment fairs as methods of unearthing future workers with the requisite skills [56]. Recruiters actively pursue those with experience of team projects, seeing an individual's ability to learn and work together as a key indicator to future employability and success.

9. OPEN LEARNING RESOURCES

Learning factories are open and shared learning facilities that are specifically designed to give learners direct experience of emerging technologies in realistic settings, and in a manner that can be tailored to particular learners, groups, and technologies. As such, they are well placed to deploy the principles of tangible, experiential, project-based learning and to support the active diffusion of innovation and knowledge. Learning factories are often built as partnerships with local government, academia and industry, and have been heralded as an important innovation by the DfE's recent "Skills for Jobs" white paper [57].

An early initiative in this direction was the *Fablabs*, which emerged from Massachusetts Institute of Technology (MIT) in 2001 as an engagement programme to make the university's state-of-the-art fabrication technology available to the general public.

Following the success of the MIT initiative, in 2007, Penn State University decided to make its own technical resources available to local industry by spinning out learning factories where engineering students could solve real manufacturing problems using state-of-the-art machinery in partnership with local industry. So successful has this model been, that, as of 2019, 120 learning factories had been established worldwide, with dozens more hard on their heels.

The US and Germany have proved the most fertile ground for the learning factory model – integrating local industry, academia, and skills provision to boost productivity and skills in the regions in which they have been established. In Germany, for example, they have served industry well, providing skilled workers in the bespoke specialisms of local manufacturers and, at the same time, providing testing grounds for the latest technologies. From the learner's point of view, *FabLabs* and *Learning Factories* build on the pedagogical approach of constructionism and the principles that have elevated "*making*" as a potent enabler of creativity, persistence and multidisciplinary problem-solving in learning through designing, making and publicly sharing objects. Learners learn by doing, with the latest technological tools.

Image reproduced with permission from: © Lehrstuhl für Produktionssysteme (LPS), Ruhr-University Bochum

Caption: There are over 50 learning factories throughout Germany. The image above is of the LFF (Lern und Forschung Fabrik) operated by LPS in Bochum. The facility provides research and teaching resources for local colleges, universities and SMEs. Its manufacturing use-case scenarios are co-designed with local industry, whose employees also share in helping participants utilise the machinery. Such learning factories are not just facsimiles of industrial factories but are specifically designed to aid learning through experience. In effect, they play the role of Industry 4.0 simulators. Learning factories are often tailored to meet the needs of local manufacturing, the Bochum LFF pictured above, for example specialises in human:robot collaboration and lean management.

Newton Rooms

Newton Rooms, initially developed by FIRST Norway in 2007 and now rolling out globally in collaboration with Boeing, operate on the same principle of making high end resources easily available to the wider public. The Newton Rooms are primarily a shared STEM resource facility for local schools, with all the latest kit for them to experiment and learn with, from chemistry labs to basic robotics. Skilled staff assist teachers to translate the technology and to support children in hands-on experience of the equipment.

Recognising the importance of taking the technology to where the people are, Newton Rooms run a mobile lab service with a mobile STEM classroom, the Mobile Newton Room, a commercial variant of the outreach engagement service initiated by the Mobile FabLabs that originally took to the road from MIT. Communities in more excluded regions in the UK may not have the resources or volition to travel to technology centres; an engagement programme in an area such as the Welsh valleys, for example, would be more effective if mobile units travelled to the valleys' communities themselves, rather than expecting these communities to travel to a city that they may not visit otherwise [58].

Having mobile versions of open resource facilities such as Newton Rooms, FabLabs and Learning Factories is not only important for getting resources to more distant parts of the country but also as an inclusion initiative. By taking the latest robotic and autonomous system technologies to the towns and urban areas most threatened by automation, and with the least skilled workforce, people can be given 'touch points' [59] to help them engage with, and be inspired by, the possibilities of the future workplace.

Whether as mobile or built infrastructure, the key is good coverage to provide enough people with access to such key resources. It is important to avoid the 'hub no spokes' [60] syndrome – whereby the UK remains strong in its top end innovation but best practice and innovative excellence can fail to trickle down to SMEs and those less connected to the centre. Outwith the enduring excellence of the UK's top few technology companies and universities, the UK's long tail of SMEs fair badly in comparison to its competitors in terms of in-house innovation and adoption of emerging technology [61].

There is evidence, however, that the UK robotics and autonomous systems sector is able to forge spokes from new hubs to bolster and develop a larger ecosystem of SMEs. The Bristol Robotics Laboratory (BRL) based at the University of the West of England (UWE), for example, has been highly successful in nurturing SMEs in its incubator, helping Reach Robotics to raise $7.8m in Series A funding, and Open Bionics raise $5.9m, as well as supporting local business with its BRL Technology Solutions programme.

Government, academia, and industry have also come together with the opening of the Robotarium at Heriot Watt and Edinburgh Universities [62]. The Robotarium aims to be a catalyst for entrepreneurship and knowledge diffusion and to offer an ecosystem of support for local industry to establish Edinburgh as a world leader in data and RAS. With a little less fanfare, but no less promising as a regional automation and skills diffusion centre, is the forthcoming opening of the new Manufacturing Innovation Hub in Motherwell [63].

Odense

The Robotarium and Motherwell hub could do worse than look to Odense in Denmark and its highly successful development of such an ecosystem around the growth of Universal Robotics over the last two decades. In less than twenty years, Universal Robotics have developed an entire market in collaborative robotics, now worth €1Bn a year, and employs close to 1,000 people, with over 700 distributors worldwide. The extent and rigour of its skills development and knowledge diffusion programmes mean that the company easily exceeded its target to train 1,000 new engineers for the Odense cluster by 2019. Including Universal Robotics, the cluster around the Danish Technological Institute in Odense numbers over 130 companies, many working in the cobotics supply chain. Twenty of its start-ups have secured investment over €20m

10. DIGITAL LEARNING RESOURCES

New digital learning technologies such as simulators, emulators, and *digital twins* can connect the *Learning Factories* and Centres of Innovation (COI) of the future as well as providing spokes to support a wider ecosystem of *SMEs. Cyber-physical systems*, made of physical infrastructure to house the technological tools of the future and their simulated cyber equivalents, can share data and digital learning resources. Smaller, cheaper, more localised mini-hubs can be enhanced by integrating them with more complex *digital twins* and the machines and tools of the larger robotics centres [64].

The increasing capability of such systems for simulation and analysis is hugely significant for future knowledge diffusion and skills provision. Virtual reality (VR), Augmented reality (AR) and the enhanced connectivity of the cloud can produce extraordinarily effective simulations of work processes and environments, while AI can work to capture and analyse learning data to continually improve the systems and offer rigorous assessment technology to learning providers.

With solely physical buildings and in-person training, developing a comprehensive network of COIs and *Learning Factories* to match those of our international competitors would be extremely costly. By contrast, an initiative that deploys digital learning technologies to enhance and supplement physical and in-person provision would be far more affordable and scalable. Digital learning technologies also mitigate the risk of hardware becoming obsolete with the fast advance of robotics and autonomous systems. As the increasing use of the Minecraft:Education Edition demonstrates, genuinely high quality gamified digital learning resources can also have real impact in engaging and educating children.

Short e-learning digital courses have proved popular with both large and small UK employers, largely for their adaptability and cost compared to more formal training. Many larger employers in manufacturing have established online training portals to deliver skills at the point of need, in bite-size chunks which can be banked as larger units of learning over time. Unable to afford such investment, *SMEs* are generally left to utilise free third-party products created by global tech corporations, or bespoke online courses in the use of particular makes of hardware [65].

Although the DfE has made a start in creating a publicly-owned online resource hub with the *Skills Toolkit*, and there are many excellent school-age online courses provided for *STEM* Learning, there remains a large gap in high-level digital learning resources for robotics and autonomous systems. With managers unable to visualise how automation could transform their workplace, graduates leaving university lacking sufficient practical know-how, and a host of potential learners currently uninspired by the resources at their disposal, a publicly-owned repository of state-of-the-art digital resources would be hugely beneficial and affordable in the short term and while larger schemes unfold.

PART 3

11. CONCLUSION

The workplace of 2030 will be a very different environment to that of ten years ago. The physical and cognitive capacity of machines will significantly disrupt the working practices and employment roles of the last decades while also offering the UK a golden chance to boost its languishing economy by embracing the transformative potential of autonomous systems.

Covid-19 and Brexit have accelerated the rise of robotics in the social and economic life of the UK. The government has shown willing to welcome such a technological transformation, but crucial to its success will be the significant improvement of its skills and educational provision, which falls far behind many of its international rivals. The current skills challenge for the UK is urgent and unprecedented.

The need to enhance technical skills at levels 4-5, management understanding of emerging technology, diversity in the workforce are burning issues facing us now, as is an education system that fails to address and provide the practical skillsets required by future employers. The excellence of many of our universities and best-performing large and small technology companies fails to reach the long tail of more distant *SMEs* and others far from the centre.

With the introduction of the new T-levels, a National Retraining Scheme, degree apprenticeships, the Skills Toolkit and an embracement of the role of *Learning Factories*, UK government is certainly responding to the challenge, but real questions remain as to whether the new proposals will be funded and scaled sufficiently to be truly effective. While such large infrastructural schemes unfold, it will be possible to implement other complementary, timely and affordable interventions.

Specifically, by providing free public access to genuinely high-end resources we can help many of our future workers acquire the skills and familiarity with robotics and autonomous systems that they will need. Managers and workers would be able to better envisage an autonomous workplace using state-of-the-art VR and AR technology. Access to the best in digital learning would also help innovators acquire more general facility with technology in order to up-scale and modernise the UK's manufacturing base.

Through the provision of robotics *Learning Factories*, graduates can be given more experience of applying their knowledge on physical machines and the best simulators. Such initiatives could also make the latest technological tools available to technicians at levels 4 & 5. The wider public could be given the opportunity to meet and interact with robots and to experience the potential of *4IR* technologies.

12. RECOMMENDATIONS

- Improve access to resources by creating a national public repository of actual and digital high-end **robotics resources**. Improving access to actual and digital high-end resources would transform the ability of many stakeholders to obtain the training and practical experience of robotics that they need in an affordable and scalable way.
- **Unspent revenues from the apprenticeship levy** could fund a national robotics resources programme. Many larger companies utilising robotics and autonomous systems may well prefer to spend their levy payments in this way, augmenting their own training resources as well as supporting the *SMEs* in their supply chain.
- Extracting best international practice from **learning factories** and local industry/skills partnerships will go a long way to augmenting the hubs of knowledge and skills diffusion in the UK, but we must, and can, now start working harder on developing the requisite **spokes** with far better public access to robotics knowledge and resources.
- **Robot learning factories** - linked together with high end digital resources such as digital twins - and **robot mobile units** should be utilised throughout the UK to give stakeholders tangible access to robots, electronics and other physical *4IR* resources. Large regional hubs can be connected to smaller local and mobile units.
- **Schools** would be ideal **mini-hubs**, with their resident technical support teams, knowledgeable teachers, solid digital infrastructure and willing audiences of children and their families. It is through schools that programmes such as STEM clubs, *NCCE's* computing hubs and Wales' *Technocamps* already operate. Schools could serve as stopping points for mobile robotics *Learning Factories*.
- **Libraries** could also be central to such a programme, serving as **mini-hubs** for accessing robotics resources, both in terms of the state-of-the-art digital learning media and of physical robots and *IoT* equipment that could be lent to local communities. Extra resource to facilitate such an initiative could help libraries find enhanced relevance and value as community resources in *4IR*, as well as providing the backbone for a mini-hub network.
- **Robots** should be utilised more in the national curriculum and in the learning life of the future workforce. Tangible contact with robots, as already demonstrated in international robotics competitions, demystifies science and autonomous systems, engages people with technology and gives vital hands-on experience of the technologies that will dominate the workplace of 2030.

13. GLOSSARY

4TH Industrial Revolution (4IR): the current industrial revolution, characterised by a harnessing of the physical and technological worlds. Fuelled by a host of rapidly emerging and highly disruptive technologies, such as AI, robotics, data science, IoT, additive manufacturing and cloud computing. 4IR follows those powered by steam, electricity and computing.

Adult Education Budget (AEB): a recent UK government-funded that can be accessed by employers and individuals to fund a range of training for learners of 19+ years old.

Artificial Intelligence (AI): Computer software that performs tasks that are normally considered to require intelligence when performed by people; examples are scene and language understanding, planning and learning.

Autonomous systems: An integrated system of machines and devices that share control programs and sensors and making decisions autonomously

BEIS: UK Government Department for Business, Energy and Industrial Strategy.

BRL Technology Solutions programme. Based at the Bristol Robotics Laboratory Centre of Excellence at the University of the West of England, the Technology Solutions programme provides services to start-ups and spinouts, linking them with academic research and other local businesses.

Cloud Computing: Computer services delivered via the internet including the remote storage of data and off-site computation.

Cobotics: collaborative robots designed to enhance the impact of intelligent automation by maximising the abilities of both humans and machines. Cobots cooperate with people, working safely with them in close proximity whereas industrial robots must be isolated from workers.

Constructionism: the educational theory that the construction of knowledge is enriched and deepened when learners build, make and publicly share objects.

Cyber-physical systems: a system in which a mechanism is controlled or monitored by computer-based algorithms. They are typically designed as networks of interacting elements with physical inputs and outputs and combine computational entities with the physical world.

Digital twinning: a digital twin is a digital replica of something in the physical world, often using 3D modelling to create digital companions for physical objects. Digital twins are used to improve operations, test new products and train people on virtual representations of real-world machines.

FabLabs: The worldwide FabLab network originated at the Massachusetts Institute of Technology (MIT) in the early 2000s with a project to give the wider community access to the latest prototyping equipment, such as laser cutters and 3D printers, and related open-source software. FabLabs have since spread to all five continents and spurred the worldwide Making movement and more recent equivalents such as Newton Rooms and Learning Factories.

FIRST: a global non-profit organisation to inspire young people and demystify STEM using robots and worldwide competitions such as FIRST Lego League, the FIRST Tech Challenge and the FIRST Robotics Competition, in which hundreds of thousands of children compete annually.

Industrial robot: A re-programmable multifunctional manipulator designed to move material, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks.

INSPIRE: an Open University-funded program working with a sample of schools to co-design how best to integrate 4IR technologies such AI, IoT and Robotics into the school curriculum.

Integrator: A company that provides automation solutions for end-users by helping them to adopt the most suitable robots and autonomous systems in the performance of their work.

The Internet of Things (IoT): a network of physical objects connected over the internet. The IoT has revolutionised business and domestic life since the term was first coined in 1999 and is expected to be among the most transformative of all 4IR technologies.

Learning Factories: are open and shared learning facilities that are specifically designed to give learners direct experience of emerging technologies in realistic settings, and in a manner that can be tailored to particular learners, groups and technologies

Making: the worldwide movement to encourage and help people to actively construct with technology rather than just consume technological products. Making has long been seen as a way to build creativity, persistence and multidisciplinary problem-solving in learning.

National Centre for Computing Education (NCCE): A national centre for computing education funded by DfE and run by a consortium made up of STEM Learning, the Raspberry Pi Foundation and BCS, The Chartered Institute for IT, with the aim to achieve a world-leading computing education.

Mechatronics: In engineering a combination of mechanical, electrical, control, computer and communication engineering.

Newton Rooms are a shared STEM resource facility for schools, developed and managed by the non-profit foundation FIRST Scandinavia to address a lack of hands-on activities, outdated equipment and shortage of resources for science laboratories in Norwegian schools. Since 2007, the network has flourished, with two rooms recently established in Scotland.

RAS: Robotics and Autonomous systems

The Skills Toolkit is a UK government-sponsored online platform launched in 2020 to help learners acquire new skills for the workplace.

Small and Medium Size Enterprise (SME): Usually defined as having fewer than 250 employees and a turnover of less than €50m. SMEs make up 98% of British companies.

STEM Learning: STEM Learning is the UK's largest provider of science, technology, engineering and maths (STEM) education and careers support to schools, colleges and community groups in the UK.

Technocamps: a highly successful computer studies (CS) skills training initiative emerging from Swansea University that now reaches thousands of children in schools throughout Wales providing resources and expertise.

WER: the World Educational Robot Contest is a global competition aiming to foster practical, creative and technological understanding, using robots.

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